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352

Forging and Tool Dressing

304 ILLUSTRATIONS

Prepared Under Supervision of

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HAND FORGING
TOOL DRESSING
HAMMER WORK
MACHINE FORGING
FORGING DIES
SPECIAL FORGING OPERATIONS

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

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HAND FORGING
(PART 1)

MANUFACTURE OF IRON

CAST IRON

1. Any iron-bearing mineral from which the metal can be abstracted at a profit is **iron ore.** This definition excludes many ores containing a large percentage of iron because they also contain a large percentage of impurities; and it will admit, on the other hand, many ores that carry a low percentage of iron, but few or no injurious elements. Iron is never found chemically pure in nature, except perhaps in some meteorites, where it is a mere curiosity, while the limited supply from this source makes it of no practical value. Chemically pure iron is soft and ductile, has a high melting point, and can be forged and welded.

The *rich ores* of iron contain from 60 to 68 per cent. of metallic iron; but those low in iron, called *lean ores*, may contain only from 30 to 40 per cent. In the United States, very few furnaces are running on ore containing less than 50 per cent. of iron. The impurities, which consist of oxygen, silicon, phosphorus, lime, sulphur, magnesia, aluminum, manganese, titanium, etc., occur in very small amounts.

2. Blast Furnace.—Iron is reduced from its ores by fusing them, together with lime, in a **blast furnace**; the lime acts as a *flux*, and is obtained by the use of limestone. A blast furnace is usually an iron shell lined with some refractory substance, such as firebrick or fireclay, and on the outside looks like a tall stack or chimney. Into it alternate layers of fuel,

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flux, and iron ore are thrown, the fuel fired, and the whole mass raised to a high temperature by means of a hot-air blast, to hasten the combustion. The blast furnace is continuous in its operation; the ore, flux, and fuel are charged into the top of the furnace, and the metal and flux melted by the intense heat are tapped out at the bottom. The amounts of fuel, limestone, and ore must be carefully calculated in order that the ore may be properly reduced. The furnace is so operated that the impurities in the fuel and ore may combine with the flux in the form of **slag,** which is lighter than the molten iron and floats on its surface. The slag is tapped from a hole at the side of the furnace, above the hearth, or bottom, while the iron is tapped from a hole at the front and bottom of the furnace and flows into iron or sand molds,where it cools. The form of cast iron so obtained is called **pig iron.**

3. Nature and Composition of Cast Iron.—The best and purest grades of **cast iron** are made in blast furnaces that use charcoal for fuel, because charcoal does not contain sulphur, while coal and coke do; and also because the ash is of such a nature that the impurities pass into the slag rather than into the iron. Cast iron, as made by blast furnaces, generally contains from 92 to 96 per cent. of metallic iron. The other 4 to 8 per cent. consists chiefly of impurities in the form of carbon, silicon, manganese, phosphorus, and sulphur, from 2 to 6 per cent. being carbon. While it is true that the five elements mentioned are impurities in iron, the first four are really the elements that make cast iron of commercial value. Cast iron has a granular or crystalline structure, and is hard and brittle. It can be cast in almost any desired shape, but cannot be forged or drawn into wire.

WROUGHT IRON

4. Wrought iron has a fibrous structure and can be forged and welded. It is made from pig iron, and while it has been practically freed, by the puddling process, from carbon, silicon, and the other elements contained in cast iron, small amounts remain, their complete removal being too costly.

5. Hand Puddling.—In the manufacture of wrought iron by hand puddling, the pig iron obtained from the blast furnace is melted on the hearth of an **open-hearth furnace** which is ordinarily of the form shown in Fig. 1. The hearth *a* is usually made of cast-iron plates carried on brick walls or on iron supports *b*. It is generally about 5 or 6 feet in length and 4 feet in width opposite the charging door, and is lined with a refractory substance. The roof is a firebrick arch. The heat is obtained ordinarily from a bituminous-coal fire in the fireplace *c*. The area of the grate varies from 6 to 10 square feet or more, depending on the character of the iron, the draft,

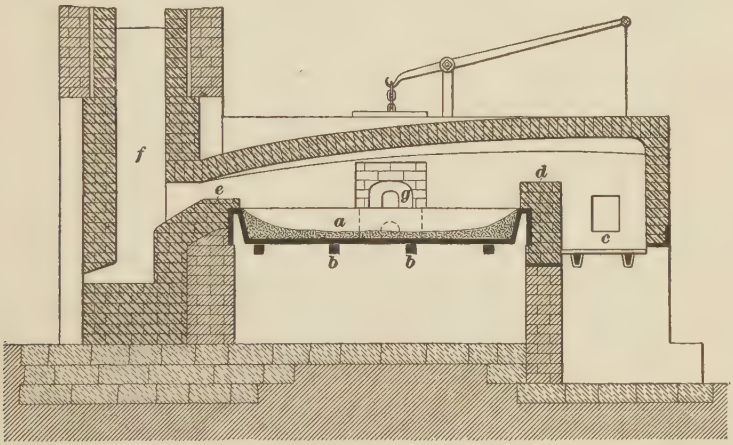

FIG. 1

and the fuel. Between the grate and the hearth is a firebrick wall *d*, called a *bridge wall*, that extends across the furnace and is of sufficient height to keep the fuel from getting over on the hearth, and the molten iron from running over on the fuel. In many cases, the bottom and sides of the furnace are hollow, and water is circulated through them to keep them cool. Another bridge wall *e*, called the *altar*, prevents the metal from overflowing into the flue leading to the chimney *f*. In the middle of the door *g* in the side of the hearth is an opening large enough to admit the puddler's *rabble;* this is a long iron bar with which the melting charge of metal and slag is stirred by the workman.

6. The furnace is charged with 500 pounds of pig iron, which is carefully placed on the bed of the furnace or is broken up and piled around the sides. When the charge is melted, the puddler stirs the fluid mass with his rabble, while his assistant changes the draft and the fire to suit the different stages of the process. The impurities of the iron are taken up by the molten flux or are burned out. In about an hour, pasty masses of metal begin to appear, which the puddler works into spongy balls weighing from 60 to 80 pounds each. These balls are well worked at a high temperature to get rid of the slag, and finally removed from the furnace and hammered or squeezed into the form called a *bloom*. The bloom is then taken to the rolling mill, and rolled into various commercial forms.

7. Mechanical Puddling.—In the various **puddling machines** in use, the flame is led from the firebox to a hearth of varying form and construction, moved by machinery. In some forms this hearth is barrel-shaped and turns on a horizontal axis. In other forms it is circular, and is so arranged that it may be mounted on a vertical shaft and rotated; but in one form the hearth slants at an angle of from 10° to 15° from the horizontal. In most cases the metal is further stirred or mixed by broad-bladed rabbles operated by the workmen or by machinery.

The advantages claimed for these machines are that greater masses of metal may be handled and that there is greater uniformity of the product, together with a saving of fuel, time, and expense. Hand puddling is also injurious to the health of the workmen.

8. Bundled Scrap.—A good deal of wrought iron is made from wrought-iron scrap, which is bound together by wire into bundles of convenient size and heated in a furnace. When the iron has been brought to a welding temperature, the bundles are removed and rolled into bars. The wrought iron thus made, however, is usually of poorer quality than that produced by the puddling process, probably because the scrap is apt to contain some steel.

9. Effect of Reheating Wrought Iron.—Experiment has proved that the strength of wrought iron is increased by repeated heating and rolling until about the sixth working. Beyond this point, each reworking decreases the strength, until, at about the twelfth. the iron will have no greater strength than after the first rolling. Careless heating may injure the iron and weaken it in one or two heats.

LOW-CARBON STEEL

10. Properties of Low-Carbon Steel.—The difference in the manufacture of wrought iron and low-carbon steel lies in the fact that wrought iron is produced by puddling a pasty mass of pig iron, squeezing out the slag, and rolling the iron into a bar, whereas low-carbon steel is produced by melting iron, pouring it into ingots, and rolling these ingots into rods and bars. The amount of carbon in low-carbon steel is generally from .1 to .5 per cent., although it may be as high as .75 per cent. Carbon gives strength and hardness, but makes the material less ductile and malleable. Low-carbon steel is used for forge work, bridge building, ship building, railroad work, and many other purposes. A grade of low-carbon steel particularly suitable for forgings contains about .1 per cent. of carbon, and is known as *mild steel*, or *machinery steel*. It is stronger than wrought iron and can be used for almost every class of work for which wrought iron is used.

11. Manufacture of Low-Carbon Steel.—Low-carbon steel may be made by the *crucible process*, the *Bessemer process*, or the *open-hearth process*. The process used will, to a large extent, determine the percentage of impurities it contains, and generally the presence or absence of other elements than carbon determines the fitness of any given steel for different classes of work.

12. The **crucible process** is used most largely for the manufacture of alloy steel and tool steel, but also some low-carbon steel is made by that process. Briefly, the process consists in charging a number of covered crucibles with pieces of

wrought iron, on top of which the desired amount of carbon is placed. The iron in the crucibles is melted and absorbs the carbon, thus producing steel with any desired percentage of carbon.

13. In the **Bessemer process,** molten iron containing a considerable amount of carbon and silicon is placed in a **converter;** this is a pear-shaped vessel with an opening in the top

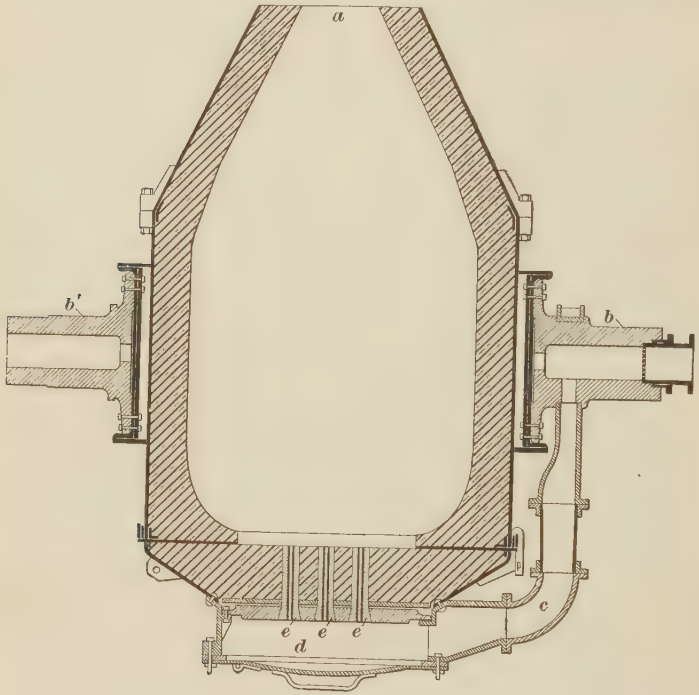

FIG. 2

at *a*, Fig. 2, and supported on trunnions *b*, *b'* so that it can be rotated. The converter is partly turned on its side and the charge of molten iron poured into it; compressed air is then admitted through the trunnion *b*, which acts as a valve, as the converter swings to its upright position. This air passes through the pipe *c* to the bottom *d* of the converter and up through the holes *e* in the lining. It rushes through the molten

metal and burns out the carbon and silicon. The air pressure must be sufficient to prevent the steel from flowing through the openings *e* into the bottom of the converter. Theoretically, the carbon can be burned out to any desired point and the operation stopped, thus producing steel containing the desired percentage of carbon; but in practice it is found exceedingly difficult. Hence, all the carbon is burned out and then the desired quantity is added by putting in an iron high in carbon.

14. In the Bessemer process, silicon, which is one of the acid elements, is burned out; hence, this process, known as the *acid Bessemer process*, is generally used, especially in the northern and central portions of the United States, where most of the pig iron is free from phosphorus and high in silicon. The pig iron from which steel is made by the acid Bessemer process must be low in phosphorus, which cannot be burned out by this method.

Bessemer steel is also made by what is known as the *basic Bessemer process*. In it silicon cannot be burned out to any great extent, and hence iron low in silicon must be used. It may, however, contain a greater percentage of phosphorus, as some of this is burned out. The converter must be provided with different linings for these two processes. As steel can be more cheaply made by the Bessemer process than by any other, it is used largely for manufacturing steel rails, structural shapes, etc.; also, for steel forgings, especially those of moderate size.

15. In the Bessemer process, the steel is made from pig iron, but in the **open-hearth process** a large portion of the charge is scrap steel that has already been purified. In the Bessemer process, air is blown through the melted iron to burn out the carbon, but in the open-hearth process the carbon is removed by a flame burning against the surface of the melted iron. The open-hearth process, therefore, requires a large surface of metal with but little depth and takes its name from the style of furnace in which the steel is made. An *open-hearth furnace* is shown in Fig. 3. The iron is heated in the hearth, or basin *a*, and the air and gas enter and the burned

gases escape alternately through flues b and c. The chambers d, d', and e, e' are nearly filled with firebrick or thin tile checkerwork containing wide open spaces. When the process is completed, the metal is drawn from the hearth through a spout at f. In some furnaces of recent design, the hearth a can be tilted toward the spout to pour the steel, the ends being stationary, as in the furnace shown.

16. The furnace is sometimes started by melting pig iron on the hearth and sometimes by using melted iron just as it comes from the blast furnace. Air is admitted through the checkerwork e, Fig. 3, gas is admitted through the checkerwork e', and the air and gas mix and burn at b. The flame

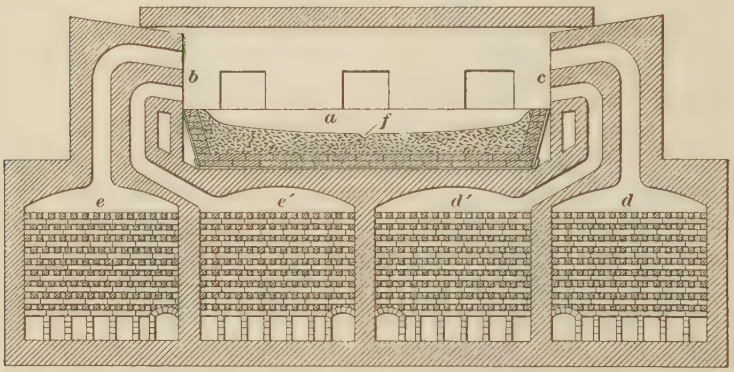

FIG. 3

is directed downwards so that it strikes the surface of the metal in the hearth, causing it to be heated to a very high temperature. The burned gas passes out at c, through the chambers d, d', heating them as it passes to the chimney. When the checkerwork in d, d' is heated sufficiently, valves that control the direction of flow of the air and gas are changed so that the air enters through d and the gas through d', and the burned gases pass out at b, heating e and e'. By thus reversing the direction of flow of the air and gas about every 20 minutes, the checkerwork can be heated to a very high temperature. The heat taken up by the checkerwork is then given up to the entering air and gas when the direction is reversed. Because

of this heat, the temperature of the flame is greatly increased; such a furnace is called a *regenerative open-hearth furnace*.

17. During the process, the carbon and impurities on the surface are burned out as the molten mass is *rabbled*, that is, worked by using a long bar. The rabbling brings to the surface the metal in the bottom of the bath and aids in producing a uniform mixture of desired quality.

During the Bessemer process, samples of the charge cannot be taken and tested; but in the open-hearth process, the charge is in the furnace for a greater length of time, and samples are taken from time to time, a quick analysis made, and the necessary changes made in the treatment to produce the desired quality. In this way, a steel of any desired composition can be made without adding carbon, which is, at best, a somewhat uncertain method. In the open-hearth furnace, as in the Bessemer converter, both acid and basic processes may be used, depending on the elements burned out. The lining must, however, be selected to suit the charging material.

18. Open-hearth steel is generally of more uniform grade and purer than Bessemer steel; but the furnace and regenerative stoves are expensive, the time required in the process is greater, and the fuel, flux, and other charging materials greatly increase the cost of production, so that this class of steel is always more expensive than Bessemer steel. Open-hearth steel, however, is of better quality and greater strength and is used where the requirements are very exacting. By exercising great care in the manufacture, a good grade of steel may be made by either process; but ordinarily the higher grades are made by the open-hearth process.

19. Defects in Ingots.—The steel as it comes from the open-hearth furnace or the Bessemer converter is poured into a large ladle and then into iron ingot molds. The surface of the metal is, of course, immediately chilled, and solidifies; the center, however, and especially the upper part, remains molten for some time. As the interior gradually cools, the sulphur and other impurities are driven toward the center, or to the part that cools last. As the metal also shrinks

considerably in cooling, a shrink hole of varying size, filled with gas, is formed in the top of the ingot, as shown at *a*, Fig. 4. When this shrink hole extends more than half way down the ingot, it is known as **piping**.

20. The piped ingot, if drawn down into a forging, will have a flaw running through its center, of a length corresponding to that of the piping in the ingot. As the gas from the interior cannot escape except by passing through the solidified surface of the metal, the hole in the finished forging will have approximately the same volume as the pipe in the original ingot. For large, high-grade forgings, a large ingot should be made and the upper portion cut off, as it contains the greater part of the impurities and any piping that may have taken place. In some ingots this piping effect is comparatively small; but for important forgings the upper portion of the ingot should never be used.

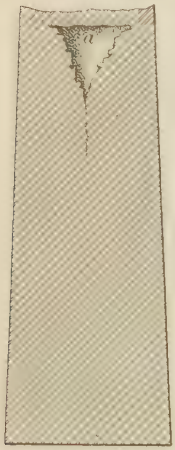

FIG. 4

21. Rolling From Ingot.—As soon as it has solidified, the ingot is usually taken from the mold and rolled to the desired shape without reheating. The rolls used for this purpose are made with a series of grooves. The ingot is first passed through the largest groove, then back through the next smaller, and so on, the size being decreased at each pass until the desired form is obtained. If a better product is desired, the rolled bars are cut into small pieces, piled in bundles, and reheated to a welding temperature. The bundles are then passed through the rolls in the same way as the ingots. This rewelding and rolling may be repeated two or three times, if desired. The bars thus produced are usually a trifle over standard size.

22. Cold-Drawn Steel.—In the manufacture of cold-drawn steel rods and bars, the rough-rolled stock is first pickled in a weak solution of sulphuric acid to remove the scale, and then passed through a lime solution to remove all traces of acid. The rough rods and bars are larger than the finished size, and

they are brought to the exact diameter desired by being drawn through steel dies. All bars up to $2\frac{1}{2}$ inches in diameter are reduced $\frac{1}{16}$ inch during the drawing process, but between $2\frac{1}{2}$ and 3 inches the reduction of size is $\frac{1}{8}$ inch. After being drawn, the bars are passed through straightening rolls, by which they are straightened and given a surface polish. The drawing operation, which is performed on the cold bar, gives the bar greater strength and a harder surface and produces a finer finish. Cold-drawn steel may be made flat, square, or round in section. It is largely used for shafting and is made in sizes from $\frac{1}{4}$ to 6 inches in diameter. The sizes from 3 to 6 inches in diameter are not cold drawn, but are turned and then cold rolled and straightened.

23. Effect of Sulphur and Phosphorus.—Sulphur in iron and steel renders these materials *hot short*, or brittle when hot. Phosphorus, on the other hand, makes them *cold short*, or brittle when cold. Sulphur also decreases the strength and ductility of steel. For these reasons, the amount of sulphur or phosphorus in forgings should not exceed .1 per cent. The grade of iron known as *Swedish iron*, which is a kind of wrought iron imported from Sweden or Norway, is practically free from sulphur and phosphorus. It is made from the richest ores and is used for special work. As it is very soft, it can easily be welded and forged.

24. Classification of Bar and Band Iron.—The width and thickness of cross-section of iron and steel determine whether the material is to be classed as bars or bands, rods or wire; but there seems to be considerable difference of opinion among manufacturers as to the limits of thickness on which the classification is based. One method of classification is as follows: Flat iron more than $\frac{3}{16}$ inch thick and not more than 6 inches wide is *bar iron;* but if it is from $\frac{7}{64}$ to $\frac{3}{16}$ inch thick, and not more than 6 inches wide, it is called *band iron.* Below $\frac{7}{64}$ inch in thickness, it is known as *sheet iron* or *sheet steel.* Stock more than $\frac{7}{64}$ inch thick and more than 6 inches wide is called *plate.* *Rods* are bars of circular cross-section not less than $\frac{3}{16}$ inch in diameter; smaller sizes are classed as *wire.*

FORGING OPERATIONS

DEFINITIONS

25. The operation of shaping or forming metal by hammering or pressing is termed **forging.**

The process of stretching a piece of metal in one or more directions, either by hammering or by pressure, is called **drawing.**

By the term **bending** is usually meant the turning or forming of the iron in such a manner as to deflect it from a straight line. The finished product may be a curved or an angular piece.

In the operation of **twisting** an iron bar, the fibers are wound around each other spirally. No change occurs in the direction of the axis of the piece.

Upsetting is the operation of increasing the thickness of a piece of iron by shortening it.

Shrinking is the operation of fastening a ring or a band on a piece, making use of the expansion that takes place when the ring is heated to a dull red. When cooling, the band contracts and grips the work tightly, if the proper shrinkage allowance has been made.

Welding is the process of uniting two pieces of metal into one solid piece by heating them to a welding heat and hammering or pressing them together. For wrought iron, a white heat is necessary to soften the metal so that it will weld.

GENERAL DIRECTIONS

26. Care of Fire.—The results obtained in forging and welding depend largely on the condition of the fire in which the work is heated. The fire must be kept clean and free from cinders or other foreign matter. The air blast should come up through the center and should pass through a solid bed of coke. The pressure of the blast should not be too great.

27. Placing Work in Fire.—The work should be placed below the top of the fire, so that the oxygen of the surrounding air cannot come in contact with it; on the other hand, it must not be placed too low in the fire, or the air from the air blast will come in contact with it. If the air comes in contact with highly heated iron, the oxygen in it will attack the metal, forming scale. If cinders and clinker are allowed to accumulate they will let the air pass freely up through the fire without burning out the oxygen, and thus are apt to cause the work to be injured. To insure even heating, the work should be placed horizontally in the fire, with the hottest part of the fire surrounding the point that is to be heated. In the case of beginners, the work should be placed in such a position that the progress of the heating can easily be observed. If the work varies in cross-section, the larger part should be heated first, and then the smaller, as the larger requires a longer time to reach the desired temperature. To insure even heating, the work should be turned over in the fire.

28. Judging Temperature by Color.—The experienced workman is able to judge the temperature of a piece of work by the color. If a piece of iron is put in the fire and slowly heated, its color will change as the temperature increases. When it has been heated to such a temperature that it has a dull-red color when viewed in a dark place, but is black when seen in the light, it is said to be *black hot*. As the heating proceeds, the piece shows a dull-red color in the light, and is then said to be *red hot*. Further heating changes the color to *cherry red*, or *bright red*, when seen in the light. As more heat is applied, the iron changes to an orange and then to a lemon color, and finally commences to spark. Just before it reaches this point it is said to be *white hot*, and has a dazzling white glow. If heating is continued, the iron will be burned.

29. Selection of Tools.—A very important point is the selection of the proper tongs to hold the work. Not only is good work impossible with tongs that do not hold it firmly, but their use is dangerous, because the hot piece of material is likely to fly out, and may hit the helper or the smith. If

tongs must remain in the fire while the work is being heated, they should be cooled off before any hammering is done on the work. A heavy hammer should not be used for light work nor a light hammer for heavy work. The hammer should come down flat, so that the corner does not make a dent in the work; this is very important in finishing.

30. Use of Sledge.—The helper, in handling the sledge, should watch the manner in which the blacksmith uses his hammer and should try to follow him. For example, when the blacksmith strikes flat on the work, the helper should strike flat with the sledge; when he strikes at an angle, the helper should strike at an angle; when he strikes heavily or lightly, the helper should strike in the same way. The paths of the sledge and the hammer are shown in Fig. 5. The sledge *a* is raised along the dotted line *b c* and descends along practically the same line, its blows alternating with those of the hammer *d*, which follows the line *b e*.

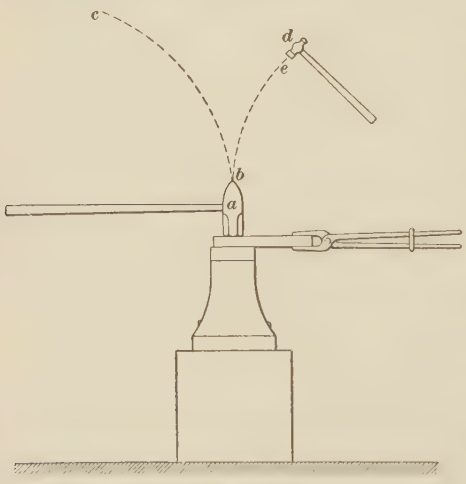

FIG. 5

31. Forging Wrought Iron and Machinery Steel. Wrought iron should be as hot as the material will stand without injury, which is close to a welding heat, and most of the hammering should be done while the work is white hot. When wrought iron cools down to a red heat it splits easily. The work should be hammered from different sides to get the same effect of the hammer blows throughout the material. The wrought-iron fibers are easily separated, and internal cracks, which do not show on the surface, may be the result of improper handling.

32. Machinery steel is more brittle than wrought iron and is therefore more difficult to forge. It should be heated carefully and should be forged at less than a welding temperature. All forging should be stopped when the steel has cooled to a dull red, and if the operation is not finished, the work should be reheated. The greater the percentage of carbon, the harder is the steel; hence, in working steel, heavier blows must be used than in working wrought iron, to produce a given effect. If a piece of low-carbon steel is heated to a welding temperature, when finished it should be reheated to a dull red and allowed to cool slowly; in fact, this practice should be followed in the case of all forgings made of machinery steel. This material can be forged at a low temperature without danger that its fibers will separate, as occurs when wrought iron is worked too cold. Machinery steel can also be punched without danger of splitting. Hence, more drawing out and forging, but less welding, is done with machinery steel than with wrought iron.

DRAWING

33. Position of Work on Anvil.—In all work on the anvil, it must be remembered that the top face is crowned crosswise, and the metal will therefore be drawn most readily in a direction at right angles to the length of the anvil. If the

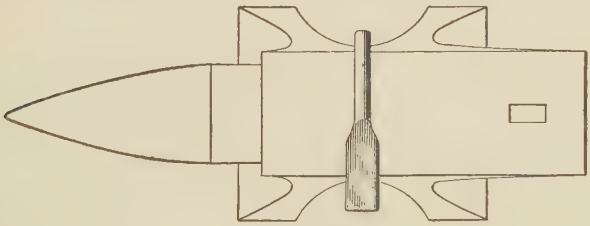

FIG. 6

piece is to be drawn lengthwise, it should be laid across the anvil as shown in Fig. 6; if it is to be drawn sidewise, it should be held as shown in Fig. 7. The drawing may be done by holding the work across the horn of the anvil; the sharper curve causes the metal to flow more freely than on the face, but it

is more likely to cause irregularities in the shape. When the work is to be straightened, it should be laid lengthwise, as shown in Fig. 7, because the anvil is straight in this direction.

34. The outer edge of the anvil, near the horn, is usually made slightly rounded, and drawing may be done by hammering the work on this part of the anvil. This method saves time, but leaves a rough job, and therefore should be used only when a considerable amount of drawing must be done on the piece. The bottom fuller and the top fuller may also be used for drawing. If the work is to be drawn out lengthwise, the fuller is set crosswise on the work; and if it is to be drawn crosswise, the fuller is held lengthwise on the work. The piece should be supported squarely under the point where the blow is struck;

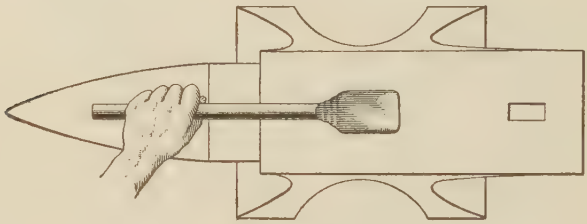

FIG. 7

otherwise, the effect of the blow will be to sting the hand holding the work. Also, there is danger that the piece may be knocked loose from the grip of the tongs.

When drawing down the end of a piece, the metal has a tendency to curve or lap over the end, which must be counteracted by striking so as to draw the metal back; otherwise, the overlapping metal will cause checks, or cracks, in the finished work and will weaken it. The temperature at which forging operations should be carried on should be from a cherry-red to a white heat, and no hammering should be done after the work reaches a dark red, except in finishing, which may be done at a black heat, using light blows. The face of the anvil should be kept clean and all scale should be removed from the work. The scale cools more quickly than the metal and is harder, and may therefore cause pits in the finished work.

35. Round Drawing.—The part of the work to be drawn is marked with soapstone and carefully heated to a white heat. It is then taken from the fire, quickly brought to the anvil, the scale removed, and the work hammered rapidly. The diameter may be reduced by two methods: first, by keeping the work as nearly round as possible during the entire process; and second, by drawing it to a square, then to an octagon,

Fig. 8

and then to a round. By the first method, the piece is turned a little after each blow and kept as nearly round as possible, and finished with the hand hammer or with a swage, as shown in Fig. 8, or by using a swage block. A second heat is sometimes necessary. The piece should be turned from left to right and then from right to left, because turning it always in the same direction is apt to twist the fibers. By this method

the iron is liable to split, to avoid which the second method is often preferred. The first method is generally used for a small amount of drawing, and the second when the diameter must be changed considerably.

36. Square Drawing.—In round drawing, the iron is turned a very little at a time, so as to bring all points under the hammer. In square drawing, however, the iron must always be turned either one-quarter or halfway around. This requires some practice, as the least variation in the amount of the turn will bring the piece out of square. In drawing a square bar down to one having a smaller section of the same shape, the sides of the original bar help to guide the hand in

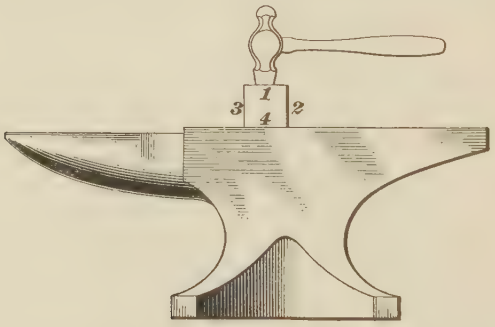

FIG. 9

making the proper amount of turn; but if a round bar is to be drawn down to one square in section, the amount of turn must be entirely governed by the hand and the eye. In drawing down a square bar to a square of smaller size, the piece is heated and brought to the anvil, one of the sides held down flat and blows struck squarely on the top side, drawing it down along its entire length. It is then revolved one-quarter of a turn and the top side hammered until the piece is about square; the opposite side is then turned up and hammered; and finally the last side is brought under the hammer. The figures in Fig. 9 show the order in which the sides are brought under the hammer. This method of turning the work lessens the liability of getting the piece twisted, or diamond-shaped, as shown in

Fig. 10. If it becomes twisted in this way, it should be held and struck in the direction shown.

37. Another method of drawing out a square, often used by experienced blacksmiths, is to heat the work to an even cherry red or a little higher, and while hammering, turn the work a quarter turn after each blow. After some hammering the work is given a half turn, and the operation is repeated. The work is thus kept more nearly square than can be done by the first method, and the fibers of the iron are less liable to be separated.

In all drawing, the work should be so hammered that the metal on the outside is not stretched more than that at the

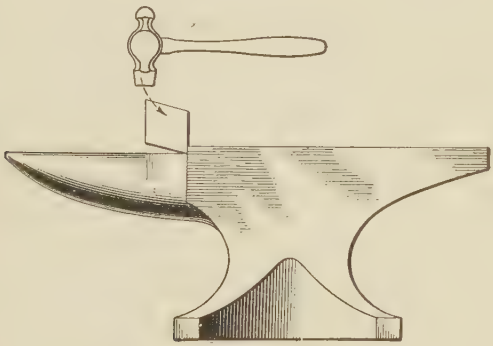

Fig. 10

center, or the end will be cup-shaped. To avoid cupping, the work should be properly heated and the blow so heavy that its effects will penetrate to the center. The heating should be done slowly, so that the work will be heated uniformly and thoroughly. The metal draws easier near the end; consequently, it is better to start drawing at the middle and work toward the end. If this is not done, the work is apt to become too small at the end before the fault is noticed.

38. Drawing to Octagon.—To draw a piece to an octagonal, or eight-sided, form, the work is first made square and measured to insure that the sides are equal. Each corner is then hammered down until the eight sides are of equal widths.

The work should be turned over occasionally, and care should be taken not to hammer it while too cold; otherwise, the sides that originally formed the sides of the square will be hollow.

39. Drawing to Hexagon.—In drawing to a hexagonal section, two opposite sides of the iron are flattened to about the required width of one side of the finished piece. Then one of these flattened places is held at an angle of 60° to the anvil face and the third and fourth sides are flattened. The piece is then turned through another 60° angle and the fifth and sixth sides are flattened. The six sides are then finished to the proper width. This forging may also conveniently be done by the use of a swage block, in which several horizontal slots are cut. The slot of the required size is selected, or, if this cannot be obtained, the one next larger. The work is heated to nearly a white heat, is laid in the slot and struck on the top. It is then turned through 60° and struck again on the top. This operation is repeated until all sides are finished. A top swage may be used in connection with the swage block, if the number of pieces required is large enough to justify the making of such a swage.

40. Drawing a Ring.—To avoid making a weld, a ring may be forged from a piece of flat stock. The stock should contain a little more volume than the desired ring. It is first cut square and then the corners are trimmed off, forming an octagon. A hole is punched through the center and enlarged until it will allow the horn of the anvil to enter. The piece is then drawn and rounded on the horn until it has the required thickness and internal diameter. This method of making a ring is particularly useful because a ring so produced is more dependable than one that is welded.

BENDING

41. In order to obtain good results, the work must be heated evenly at the point where it is to be bent. The best heat to be used is close to a red heat, but this varies somewhat with the composition of the iron. Too high or too low a heat will not give the required results. For instance, a piece

will sometimes bend more easily at the place where it is red hot than where it is white hot; therefore, an even red heat is necessary at the place where the bend or twist is desired. Small sizes of rods may be bent easily by inserting them in the hardie hole or the pritchel hole of the anvil to the point at which the bend is desired, and bending the end over. Some pieces may be bent by doing the work entirely over the face of the anvil, whereas other pieces are bent over both the horn and the face of the anvil at various stages of the operation.

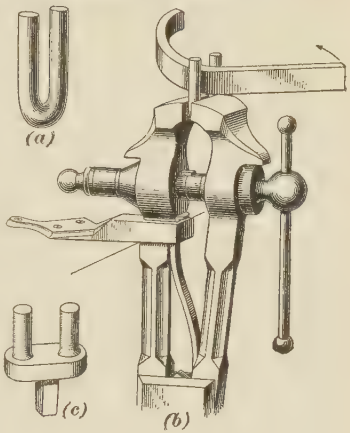

FIG. 11

42. A very good way of bending iron for a band ring, or for a similar piece, is to use a piece of $\frac{1}{2}$-inch or $\frac{3}{4}$-inch round iron bent into **U** shape, as shown in Fig. 11 (*a*). This piece is clamped in the vise with the open end up, and the iron to be bent is laid between the projecting ends and bent by pressing

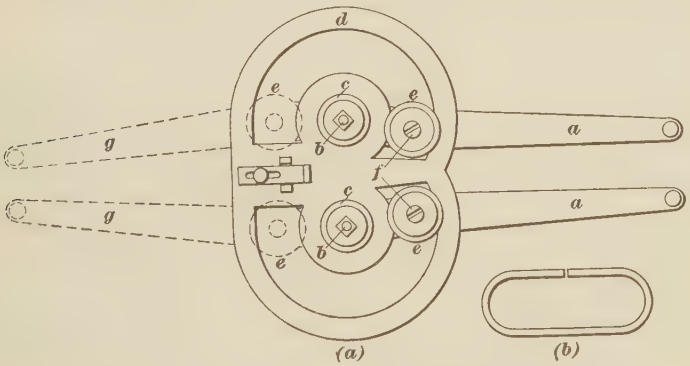

FIG. 12

the end sidewise, as shown in (*b*); or, a fork that has a square shank to fit the hardie hole of the anvil, as shown in (*c*), may be used. The iron may be bent either hot or cold. If the iron

is thin, it should be bent cold, as hot bending is liable to kink it. If thin iron is bent hot over the horn of the anvil, the jarring from the hammer blows is also apt to make the projecting end sag and lose its shape.

43. If a large number of pieces are to be bent to the same shape, a former of special design should be used. A former intended to produce elliptic links is shown in Fig. 12 (*a*). It consists of two arms *a* that are pivoted on the pins *b* on which the rollers *c* are set, but on the opposite side of the frame *d*. The arms carry rollers *e* that can turn freely on the pins *f*. To use the device, the arms *a* are swung around to the opposite side, as shown by the dotted lines *g*, and a straight piece of wire of sufficient length to form the link is placed between the rollers *c* and *e*. Then the handles or arms are swung around to the position shown, and the wire is bent around the rollers *c* to the desired form, as shown in (*b*). An adjustable stop is added between the rollers *e* at the left, to keep the wire from bending back.

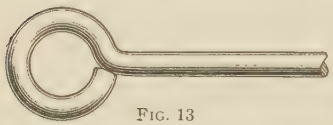

FIG. 13

44. Eye Hanger.—Suppose that it is desired to form the eye pipe hanger shown in Fig. 13, to support a pipe $1\frac{1}{4}$ inches in diameter; the eye is to be bent to the form shown, but not welded. A rod $\frac{1}{2}$ inch in diameter and slightly over 2 feet long is marked at a distance of 6 inches from one end; this end is then heated to a bright red up to the point marked. The cool end of the rod is grasped with the left hand, and the marked point on the heated end is placed over the farther edge of the face of the anvil, or over the horn near its point. The heated end, which projects, is then bent down so that it points nearly at right angles to the rest of the rod. The rod is then turned

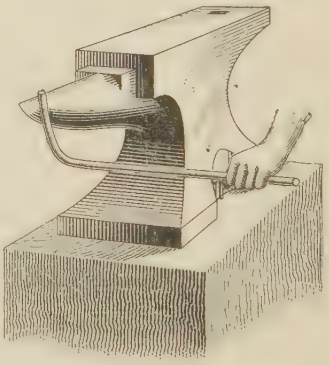

FIG. 14

on its axis halfway around so that the heated end points up instead of down. The extreme end of the heated part is then brought down so that it projects slightly over the end of the horn, as shown in Fig. 14, and the end of the rod is bent gradually by light hammer blows into a ring, as shown in Fig. 13. If desired, it may be shaped around a pin of suitable diameter, used as a mandrel.

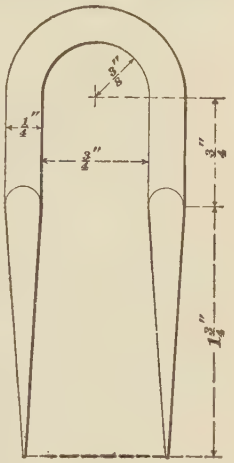

FIG. 15

45. Forging a Staple.—If a staple, like the one shown in Fig. 15, is to be made from a piece of $\frac{1}{4}$-inch round iron, the required length is first marked off on the bar. On this, a distance of 1 inch from the end is marked off, and the end is heated and drawn to a square point $1\frac{3}{4}$ inches long. The piece is then cut off from the bar, using the hardie, as shown in Fig. 16, and making the piece $5\frac{1}{2}$ inches long, over all. The other end is marked and drawn out to a point the same as the first, keeping both squares in line. The piece will now be about $6\frac{1}{4}$ inches long, $\frac{1}{4}$ inch round in the middle, with a square tapering point $1\frac{3}{4}$ inches long at each end. The center of the piece is then marked and heated, and the piece bent over the horn of the anvil to the shape shown in Fig. 15, making the distance between the two straight, parallel ends $\frac{3}{4}$ inch. In bending over the horn of the anvil, the piece is held against the large part of the horn and

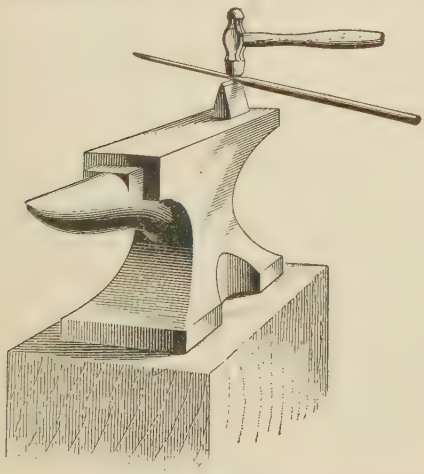
FIG. 16

bent by light hammer blows, turning it to keep it round; then while hammering it the piece is gradually brought toward the point of the horn. When bent, the curve should be uniform

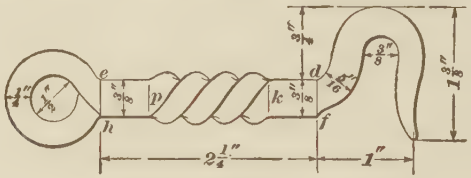

Fig. 17

and the two ends of the same length. If it is warped or twisted, it is flattened on the anvil with the hammer or the flatter.

46. When drawing the stock for the staple to a point, great care must be taken to avoid splitting. After heating it to a very bright red, drawing is started from the end, working from two sides in order to make a square point. The work should be held at an angle to the anvil and struck at the same angle to the anvil. If the piece must be replaced in the forge for a second heat, care must be taken not to overheat the drawn-out part, which will heat more quickly than the larger body, especially when the point is slender. The work should not be hammered when below a red heat, or it will very likely split.

TWISTING

47. Forging a Gate Hook.—If a hook, like the one shown in Fig. 17, is to be made of ½-inch square iron, the operation will be about as follows: As about 4 inches of stock is required to make the hook, this length is marked off from the end. It is

Fig. 18

then heated and drawn out until it calipers ⅜ inch square, when it will be about 5½ inches long. A length of 1¾ inches is then marked off from the end and drawn first octagonal

and then to a round of $\frac{5}{16}$-inch diameter, keeping one side straight, as shown at *d*, Fig. 18. The shoulder, or offset, *f* is formed over the edge of the anvil, as shown in Fig. 19. By striking the upper edge with the hammer, as shown, the top will remain straight at *d*, after which it can be finished with a swage to make it perfectly round. A length of $\frac{3}{4}$ inch is then marked off on the $\frac{5}{16}$-inch end and the point drawn down round, as indicated by the dotted lines, Fig. 18. The entire piece is then cut from the bar and the other end of the $\frac{3}{8}$-inch square marked off, making the distance between the shoulders $2\frac{3}{4}$ inches, and drawn to $\frac{1}{4}$ inch round, keeping it straight at *e* and forming a shoulder at *h*. The $\frac{1}{4}$-inch round part is bent into a ring over the horn and the $\frac{5}{16}$-inch round end is bent into the hook, as shown in Fig. 20. In bending the hook and the ring, the piece is held with one round end projecting over the farther edge of the anvil, and this projecting end is bent back until it has the shape shown in Fig. 21. The other end is then bent in the same way, and the ring and hook formed over the horn

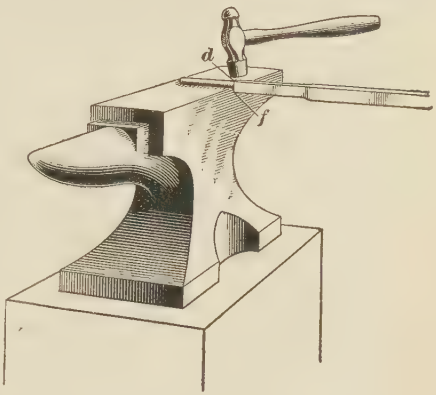

FIG. 19

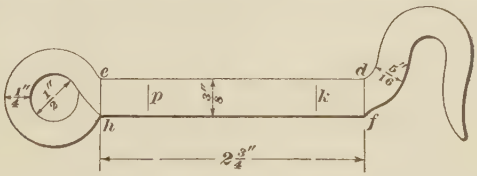

FIG. 20

of the anvil by light hammer blows, which should not fall directly on the place where the work rests, but a little beyond this point. The stock will thus be bent without destroying its shape.

48. Twisting the Hook.—Lengths of $\frac{1}{2}$ inch are now marked off with a prick punch on the square part from the shoulders f and h, giving the points k and p, Fig. 20. The

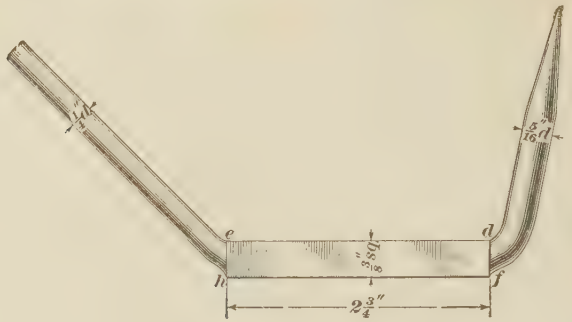

Fig. 21

portion between k and p is then brought to an even red heat and twisted. To do this, the piece is clamped vertically in the vise by the hook end, as shown in Fig. 22, with the point k at the top edge of the vise jaw, and a monkey-wrench is fitted to the ring end, immediately above the point p. The wrench is then given one complete turn, twisting the square part as shown in Fig. 17. If it has become bent, it may be straightened by hammering it between two blocks of wood on the anvil so as to avoid battering the sharp edges. For light work, two pairs of flat tongs may be used for the twisting, one pair to take the place of the vise and the other pair to do the turning.

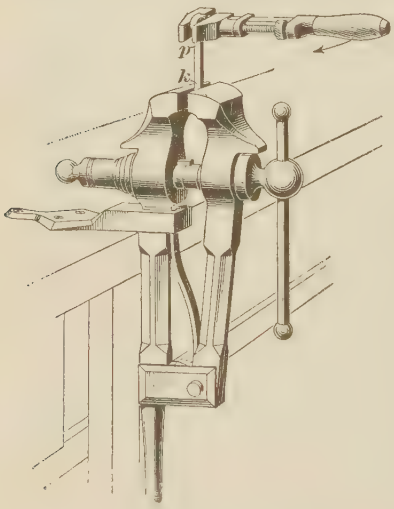

Fig. 22

UPSETTING

49. Ramming.—When it is desired to upset, or thicken, a portion of a piece of iron, this part is heated to almost a white heat, the rest of the bar being kept cool by pouring water over

FIG. 23

it with the sprinkler, or by dipping it in water. When sufficiently heated, the piece is brought to the anvil and upset, either by ramming or with the hammer.

If the bar is from 2 to 3 feet long and is to be upset at the end, the heated end of the bar is rammed against the face of the anvil, as shown in Fig. 23, or on a block of iron bedded in the ground, called a *bumping block*. The entire energy of the blow is concentrated at the hot end of the rod, and drives the particles of the iron near the end together in the direction of the blow, thus bulging out the iron where it is hot.

Fig. 24

50. Upsetting With a Hammer.—If the bar is short, it may be brought to the anvil with a pair of tongs, as shown in Fig. 24, and held vertically on the anvil with the hot end up and the heated end hammered, or with the hot end down and the blows struck on top of the cold end. By the second method, the heated end is constantly in contact with the cold face of the anvil and will therefore cool very rapidly; consequently, the bar will spread less at the end, but the bulge will

extend up a little further than by the other method. In the same manner an upset may be made at any point on the bar by heating the place to be upset, while the remainder is cool.

FIG. 25

51. Precautions in Upsetting.—If, in upsetting a bar, it begins to bend after a few blows have been struck, the piece must be straightened at once, for any blows struck endwise on a bent bar will have little effect in upsetting it, but will only bend the bar more and make the straightening harder;

FIG. 26

therefore, good square blows must be struck. For upsetting, a good heat is required; in fact, it is well to make the final heat a welding heat, because upsetting often separates some of the

fibers, and by taking a welding heat over the piece and hammering it on the sides a little, all loose fibers will be welded together again.

52. Square-Headed Bolt.—If a $\frac{1}{2}$-inch bolt, Fig. 25, is to be made from a $\frac{1}{2}$-inch round rod, the end of the rod is heated and upset. Bolts should be headed at as near a welding heat as the iron can be worked. When enough metal has been upset to form the head, the cold end of the bar is passed through a suitable hole in the swage block, or through the heading tool. If the latter is used, it is laid on the anvil so that the body of the bolt passes through the hardie hole. The upset end is then hammered down against the swage block or heading tool, as shown in Fig. 26, until the head is $\frac{9}{16}$ inch thick, and the piece is driven out of the heading tool. The head is then shaped square with a hand hammer. If, after the sides of the head are properly formed, it is found that the head is longer than it should be, it is laid on a piece of soft iron placed on the anvil and the extra length cut off with the hot cutter. The bolt is then put back into the heading tool and the head is finished with the hammer; the bolt is then cut off to the desired length, and the *burrs*, or rough edges, on the end are hammered down.

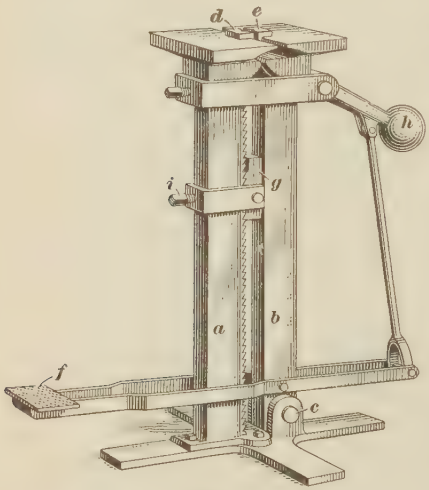

FIG. 27

53. A **bolt header,** shown in Fig. 27, may be used in upsetting the end of the bar to form the stock for the head. It consists of two uprights *a* and *b*, the latter of which is pivoted on a pin *c* so that its top can be swung toward or away from the top of the upright *a*. The dies *d* and *e* are set in the tops of the

uprights and are forced apart by pressing on the pedal *f* with the foot. The heated stock for the bolt is then set between the dies, with its lower end resting on the adjustable block *g*, and the pressure on the pedal is relieved. The weight *h* then falls, moving the tops of the uprights together and closing the dies around the upper end of the bar, which projects somewhat above the dies. This heated projecting end is then hammered down to the desired thickness of the bolt head, after which the dies are moved apart and the bolt taken out. The machine is provided with a set of dies to suit stock of different

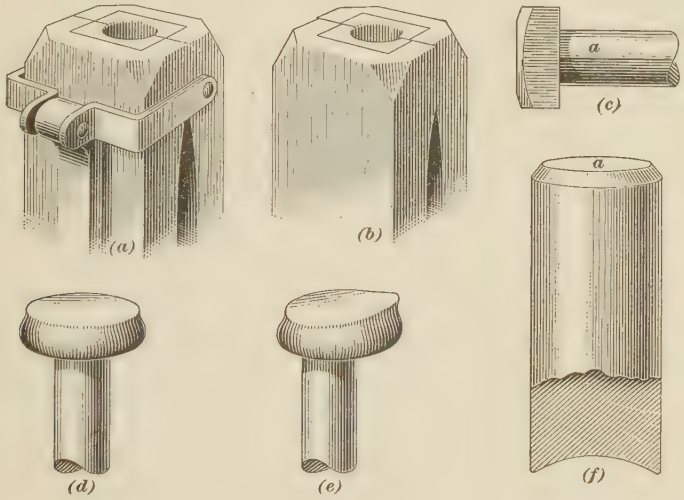

FIG. 28

sizes. Bolts of different lengths are accommodated by moving the block *g* up or down and clamping it in place by the screw *i*.

54. When in use, the dies of the bolt header should be carefully set in line, as shown in Fig. 28 (*a*). If they are out of line, as in (*b*), fins will be formed along the opposite sides of the bolt, as at *a* in view (*c*). Pieces of sheet iron may be inserted at the sides of the dies to bring them into line. Blows should fall squarely on the end of the bar to be upset, and the finished work will then appear as in (*d*). If the blows are not square, the head will be formed to one side, as in (*e*). After

the bolt has been upset, as shown in (*d*), it is taken out of the machine and squared on the anvil, after which it is put back in the header and hammered to bring the head to the correct thickness. A tool like that shown in (*f*) is used finally to round the surface of the head; it is set on the upset head and struck on the end *a*.

55. The iron must not be burned by overheating, or the part of the bolt just beneath the head may be wasted away and become too small. The same defect may be caused by using too small dies. The stock for the bolt should be heated far enough from the end to allow the dies to grip hot metal; otherwise, it will not upset properly and will form a weak head. It should not be heated too far, however, or it will buckle between the dies and the supporting block, making the upper part too short. The edges of the dies should be rounded slightly, so as to leave a fillet where the stem of the bolt joins the head. The upsetting should be done at one heat, if possible. The size of a bolt is given by stating the diameter of the stem and its length under the head. For example, a $\frac{3}{4}$-inch bolt 8 inches long has a stem $\frac{3}{4}$ inch in diameter and 8 inches long, measured from the under surface of the head to the end of the bolt.

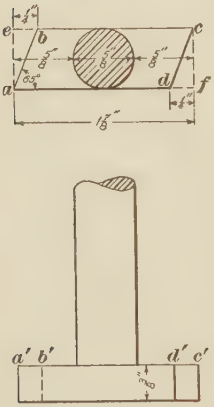

FIG. 29

56. T-Headed Planer Bolt.—Suppose that a planer bolt of the size and shape shown in Fig. 29 is to be made from a $\frac{5}{8}$-inch round rod. The operation consists in alternately upsetting the end and forging it to the oblong form of the head indicated by *a e c f* in the top view. The points *a b c d* of the head in the top view correspond to the points *a′ b′ c′ d′* in the side view. The end of the rod is first heated and upset; the upsetting must alternate with hammer work to keep the sides *a f* and *e c* parallel. For the latter, the bolt is laid flat on the face of the anvil with first one side *e c* placed uppermost to receive the blows of the hammer, and then the opposite

side. Also, the head is frequently moved beyond the edge of the anvil and is struck with the hammer for the purpose of both forming and upsetting it.

57. The process of upsetting and forming is continued until the amount of metal upset is sufficient to form the desired head. This is then heated and the cold end of the rod is passed through the right size of hole in a swage block, or through a heading tool, and the inside face of the head is worked to shape. But this latter cannot be done at one operation, for the side faces, shown in the top view at *a e* and *c f*, Fig. 29, must be brought to shape with the hammer. The final shape of the head, shown in the top view by *a e c f*, is obtained by dressing the side faces *a e*, *e c*, *c f*, and *f a* and the end face of the head with the hammer, and by finishing the inside face on the swage or heading tool. The lengths *e b* and *f d*, each equal to $\frac{1}{4}$ inch, are marked off with a soapstone pencil or a hand chisel and the

FIG. 30

portions of the head *a e b* and *c f d* are then cut off with the hot cutter. The angles *b a d* and *b c d* are approximately equal to 65°, and hence if the bevel is used it may be set to this angle and used to test the angles between the faces. It is not desirable that the edges at *a* and *c* be made sharp. The head of the bolt is made thin so that it will break off before the pressure becomes great enough to injure the lip of the **T** slot in the planer table.

58. Making a Hexagonal Bolt Head.—If it is desired to form a hexagonal head on a $\frac{3}{4}$-inch bolt of the dimensions shown in Fig. 30, the end of a $\frac{3}{4}$-inch round rod is heated and upset. When enough metal has been upset to form the head, the cold end of the bar is passed through a suitable hole in the swage block or the heading tool, and the inside face of the head is surfaced around the shank of the bolt as described for a square-headed bolt.

The head is then shaped in a three-sided groove of proper size, which is usually formed on the edge of the swage block. The swage block is placed so that the groove is horizontal and the opening is on top. The inside face of the head is trued up, as before, and the side faces are again touched up with the swage, after which the head, if it is too long, is marked for the proper thickness and the end cut off with the hot cutter. A hand hammer is also used in the final dressing of the head. A cup-shaped swage may be used for finishing the top of the head into the rounded shape shown in Fig. 31. The bolt is finally cut to the proper length, which in this case is 5 inches, and the burrs on the edges are dressed down with the hammer.

FIG. 31

Iron bolts can be made from bars of the same diameter as the diameter of the bolt, the heads being made by welding on rings or by upsetting the stock. Tool-steel bolts must be made from bars as large or larger than the head, and the body drawn down to the required size.

59. Making a Small Chain Hook.—If the chain hook, shown in Fig. 32, is to be made from a bar of $\frac{1}{2}$-inch round iron, about $6\frac{1}{2}$ inches of stock is required. The end must be upset to provide stock for the eye of the hook. To provide enough stock to make the eye, a length of $1\frac{1}{2}$ inches is marked off from the end of a bar, and the end heated and upset until the original $1\frac{1}{2}$-inch length is shortened to 1 inch. The piece is then flattened down to $\frac{3}{8}$ inch in thickness, making the upset portion circular and about 1 inch in diameter, as shown in Fig. 33.

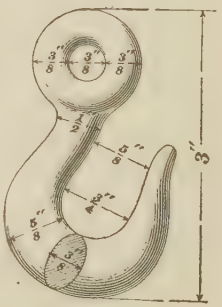

FIG. 32

60. In flattening the upset portion to $\frac{3}{8}$ inch in thickness, it should be spread sidewise as much as possible. If it draws out in length, it may be upset a little in a swage or heading tool, or on the edge of the anvil, as shown in Fig. 34. When the head has been formed, it is heated, and a $\frac{1}{4}$-inch hole put through

with the punch, which should be kept cold by dipping it in water before and after it is used. After the hole is started, the punch is held aside to see whether it is in the center; if it

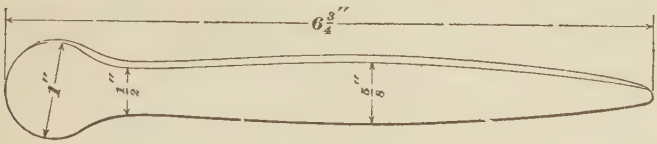

Fig. 33

is, the punch is driven down well and the piece is turned over and punched from the other side, where the iron shows a black circular spot. The core is driven out through the hardie hole or through the pritchel hole. Some smiths put a little coal or coke dust into the hole after it has been started and then finish the hole by driving the punch on top of it; the point of the punch is thus kept cool and prevented from sticking in the hole.

61. When the hole has been punched, the eye of the hook is raised to a welding heat and worked over to weld up any parted fibers or split places. For this, the punch is put into the hole and left there while hammering the eye. The punch is driven down occasionally to keep it tight; the hole will thus be spread to about $\frac{3}{8}$ inch in diameter.

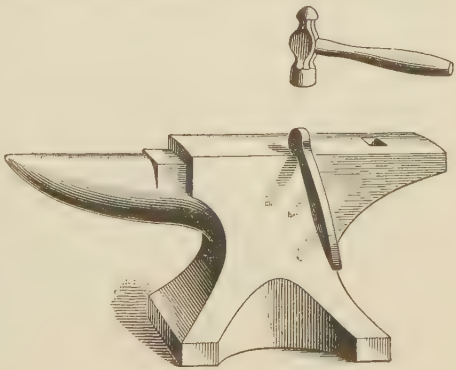

Fig. 34

Another method of making the eye is to take a sufficient length of material to form the eye of the hook by bending the end of the rod around a pin, a mandrel, or the end of the horn of the anvil. The eye end of the rod is first scarfed as shown at *a*, Fig. 35 (*a*), and is bent around to form the eye as shown in (*b*), after which the end is welded

These latter operations will be described in detail in connection with welding operations.

62. The first step in bending the hook to shape is to bend the point, or small end. Then the heavier middle section is

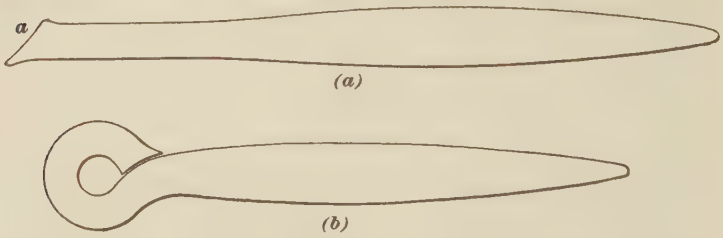

FIG. 35

heated, the point is dipped in water to cool it, and the body of the hook is bent over the horn of the anvil, at a point about one-third the distance from the tip to the eye. The work is then turned over so that the back rests on the anvil and blows are struck near the tip, thus completing the bend and closing the hook to the desired amount. Finally, the neck is heated and bent over the horn of the anvil so that the center of the eye and the point where the load hangs on the hook will be in the same vertical line when the hook is in use.

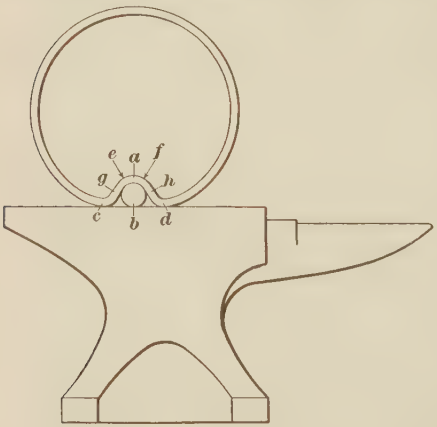

FIG. 36

To reduce the labor of forging, a chain hook may be made of flat stock. One end is formed to the shape of the point of the hook and a hole for the eye is punched at the other end. The neck is formed by laying the piece edgewise on a bottom fuller, placing a top fuller on the upper edge, and striking it with a sledge. The eye is then rounded over the horn of the anvil,

the neck is rounded and tapered out into the body of the hook, and the heavier section is forged to a wedge shape. The bending is then done as already described.

63. Upsetting a Ring.—If a ring stretches or is made too large, it may be made smaller by the process of upsetting. One way of doing this is to heat a part of the ring to a bright red, as at *a*, Fig. 36, lay it on a piece of round iron *b* and bend it over this piece as shown. It is then set in the vise and gripped by the jaws at the points *c* and *d*, so that the bend *a* projects above the jaws, and is struck at the points *e* and *f* in the directions indicated by the arrows. The hammering at *f* upsets the metal at *g* and that at *e* upsets the part *h*, thus shortening the ring. The ring is now removed from the vise and the bend is hammered back to its original shape over the horn of the anvil. The amount of upsetting done in the vise should be somewhat more than is required to bring the ring to the desired size, as there will be some stretching when the ring is hammered back to shape.

SHRINKING

64. When a piece of iron or steel is heated, it grows larger, and when it cools, it shrinks. This action is made use of when parts of machines are joined or held together by shrinking bands or rings around them. The band or ring is first made of the required size and shape. When cool, it is a little too small to fit over the pieces to be joined. It is heated to a red heat, and the heating causes it to expand about $\frac{1}{64}$ inch for each inch of length. This increase of size allows it to be slipped into place over the pieces that are to be held together. As the ring cools, it shrinks, and in so doing it grips the pieces tightly and draws them together very firmly.

HAND FORGING
(PART 2)

FORGING OPERATIONS—(Continued)

RIGHT-ANGLED BENDS

1. Making Sharp Corner.—If a bar of $\frac{3}{8}$-inch square iron is to be forged into a right-angled bend with a sharp corner, like that shown in Fig. 1, the bar must be upset at the center in order to give the additional stock required for the corner. About $8\frac{3}{4}$ inches of stock is cut off, and the center is heated and upset to $\frac{5}{8}$ inch in diameter, as shown in Fig. 2. The piece is then bent at right angles in the center by sticking one end through the hardie hole down to the heated center and bending the other end toward the anvil, as illustrated in Fig. 3. To make

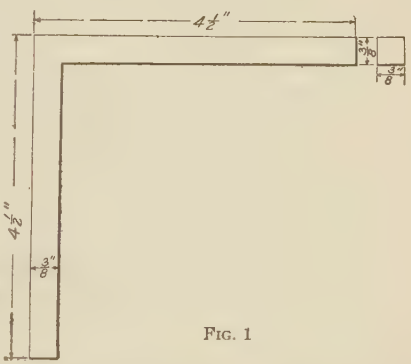

FIG. 1

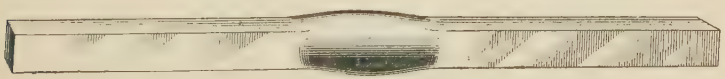
FIG. 2

the corner sharp, the piece is held on the face of the anvil, as shown in Fig. 4, and the angle made true by hammering. When

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striking the blows the hammer is drawn as shown by the arrow; this draws the iron toward the corner.

2. Care should be taken not to start a nick on the inside of the bend, because this will break some of the metal and start a crack. When this crack is closed up by forging and by the contraction of the metal during cooling, it cannot be seen, and

FIG. 3

then forms what is called a *cold shut*. To avoid this, the piece should be hot enough to bend well and should be bent over a rounded place. The angle should be kept a little larger than 90° until the outer corner is forged sharp, and then closed up to a right angle. The piece is finished $\frac{3}{8}$ inch square with the flatter, and the ends are cut to equal lengths on the hardie, and then squared with the hammer.

3. Besides upsetting, several other methods of obtaining a sharp corner may be practiced. Welding in a piece, as indicated in Fig. 5, is a quicker process than upsetting, and if correctly done makes a good, solid corner. The piece is bent, the inside angle squared, a gash cut in the piece with a hot chisel, and a blunt, thick wedge driven in and welded, after which the outside corner or angle is made square.

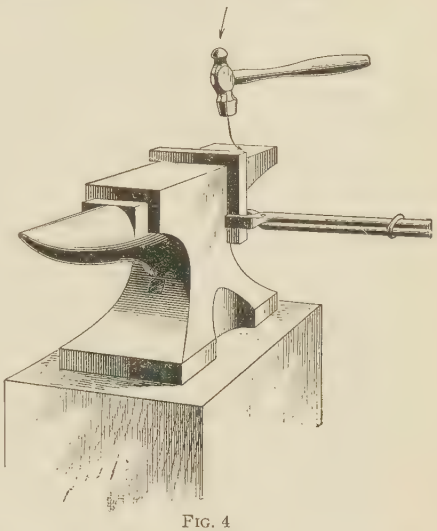

FIG. 4

Another method often used is to split partly through the center a piece of twice the required width, as shown in Fig. 6. One upper corner is cut off and the one half is bent out and up until it is at right angles to the other half. The outside of the corner is then squared.

4. Forging a Rod Strap.—To make a rod strap of the form shown in Fig. 7 (*a*), it is necessary to use stock of the width shown at *a* in (*b*), and thicker than *b* by a sufficient amount to form the corners *b*, view (*c*). This stock is drawn to the form shown in (*c*), leaving the sides slightly thicker at *c* than they will be in the finished strap, as they will draw in the bending, and being careful that the hammer leaves no ridges, which would tend to start cracks, sometimes called *gaulds*, in the corners, which become deeper as the work progresses. Next, the stock is gripped in the tongs, and while held as indicated in (*d*), is bent,

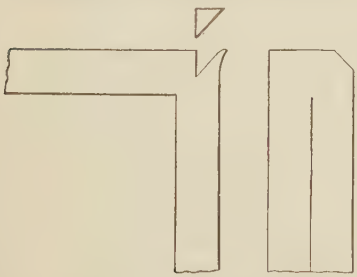

FIG. 5 FIG. 6

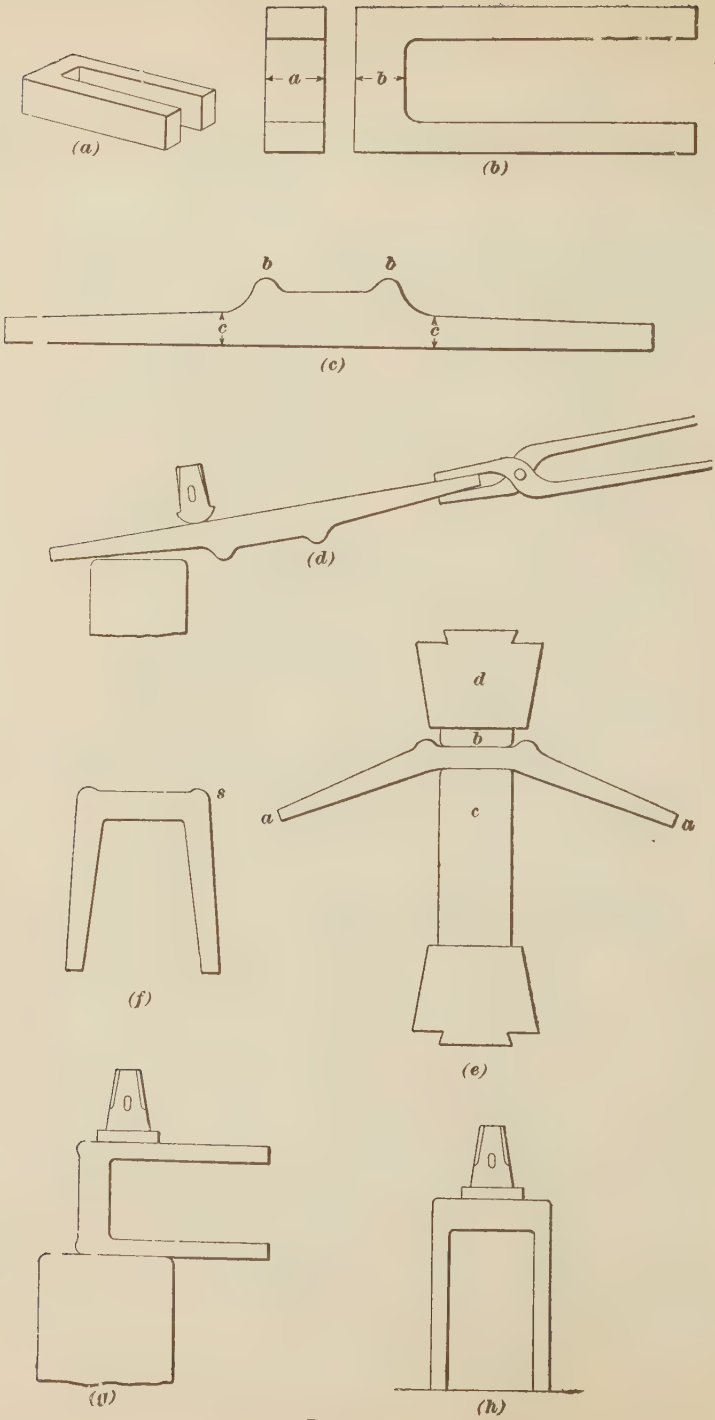

FIG. 7

using a large fuller to start the bend, as by starting in this way the iron is not cramped at the corners. Any ridges left by the hammer may be taken out by the fuller when starting the bend.

5. After the bends have been started as shown in Fig. 7 (*d*), the stock may be held in the steam hammer in the manner shown in (*e*), by lowering the upper die *d* on the upper one of two blocks *b* and *c*, between which the stock is placed, and holding it firmly by means of the steam pressure. Next, two helpers, one on each side, strike simultaneously on the ends until the piece has the form shown in (*f*). A heat is taken on one corner by placing the side *s* down in the fire, and by using the flatter, the side is brought to the shape shown in (*g*), and this is repeated on the other corner and side. During this operation the flatter must be used on the strap, which is held as indicated in (*h*), in order to make the end of the proper shape. If no steam hammer is available, the stock may be bent over a mandrel of suitable size or over a square bar held in the vise.

WELDING

CONDITIONS GOVERNING WELDING

6. Object of Welding.—It is often necessary to join together two pieces of iron, or the ends of the same piece, so that the joint will form one solid mass. In such cases, the pieces are welded together.

Each of the pieces treated thus far has been made of a single piece of iron, but very frequently it is inconvenient or impracticable to make the forging from one piece. In such cases, several pieces are welded together, and the forging is said to be *built up*.

7. Oxidation of Iron.—A piece of iron heated in air absorbs oxygen from the air, thus forming a **scale** of oxide of iron on the surface. The hotter the iron, the more rapidly the scale will form. It does not stick to the iron very firmly, but surfaces coated with it cannot be welded. It is therefore

very important to guard against scale on the iron if a weld is to be made, because the scale will lie between the two surfaces of the iron and prevent their coming in contact; and if it is not made fluid it will not squeeze out when the pieces are pressed and hammered together. Two methods are employed to guard against the oxidation, namely, the use of a *reducing fire* in heating, and the use of suitable *fluxes*. By both of these methods the oxygen of the air is prevented from coming in contact with the hot iron and thus forming scale.

8. Reducing Fire.—A **reducing fire** is one in which all oxygen is used in the combustion, so that the gases coming in contact with the iron contain no oxygen that can unite with the iron. Hence, no oxidation can take place, and no scale is formed. This condition is obtained in a closed fire by having a thick bed of fire for the air to pass through before coming in contact with the iron and by maintaining a moderate blast. If, however, the blast passes through a thin bed of fuel or if more air is blown through than the fire needs, the unused oxygen will oxidize the iron. Therefore, a thick fire should always be maintained, and the blast regulated so as to supply just enough air and not too much.

9. Fluxes.—The other method of preventing oxidation is to coat the surface of the iron with some substance that will exclude the air. It must, of course, contain no oxygen that will unite with the iron. It must be fluid at a heat below the welding heat of iron and still not become so fluid at the welding heat that it will run off and leave the iron exposed as before.

Substances used to prevent the formation of scale on iron that is being heated for welding are called **fluxes.** Most of them form a fusible mixture with the iron oxide, which affords the desired protection to the iron; but to make this mixture some of the iron is used up and therefore wasted. This mixture is so liquid that it can be squeezed from between the surfaces being welded, which are thus left clean.

10. There are many kinds of fluxes, some of which consist of mixtures of several substances. The most common flux for

wrought iron is clean sharp sand, which fuses readily on the surface of the iron and sticks to it during the heating, thus excluding the air. A very good flux for iron, but one that cannot be used on steel because it tends to reduce the carbon, can be made by mixing 2 ounces of calcined borax and 1 ounce of sal ammoniac. The welding of steel is a difficult operation, and the best of fluxes should be used; hence, **calcined borax** is commonly employed as a flux for steel. It is made by heating borax in an iron pot until the water is driven off. The mass is then cooled and pulverized. Calcined borax is also called *borax glass*.

11. Sand and borax are very good fluxes for iron alone; but it is well to have a flux that can be used when welding steel to iron. A very good flux for welding steel to iron is made of potter's clay, wet with strong brine. This is dried and powdered and used like sand or borax. Another good flux that is not too fluid, and does not injure steel, is made by mixing 3 ounces of carbonate of potash, also called *pearlash*, with 1 ounce of dry clay. This is heated in an iron pot, and when hot, 4 ounces of calcined borax is added. When cold, it is powdered, and is then ready for use.

12. Welding of Steel.—When welding steel, great care must be taken to keep the fire deep and clean and not to use too strong a blast. If steel is to be welded to wrought iron, the pieces must be heated to different temperatures. Both are brought to a red heat and borax or some other flux is put on them. The heating is continued until the iron is white hot and the steel has a bright yellow color. Then the pieces are withdrawn, put together, and welded with quick sharp blows. Mild steel can be made white hot, but care must be taken not to burn it, as its strength and toughness will be largely destroyed. Steel containing more than 1 per cent. of carbon may be brought to a yellow heat; but if the percentage of carbon is greater, only a cherry red should be used. Steel containing more than $1\frac{1}{4}$ per cent. of carbon is hard to weld, but the welding can be done if the proper care is taken with the fire, the heating, and the fluxing. One way of determining when the pieces have

been brought to the proper temperature for welding is to run the poker over them while in the fire. If the poker sticks to the work, the correct temperature has been reached.

13. Tool steel, while being heated for welding, should be kept from the air. A low welding heat is required, and the steel should be heated in a coke fire. If coal is used, the sulphur in it will make welding impossible. The flux for tool steel may be made of $\frac{1}{4}$ pound of borax, $\frac{1}{4}$ pound of carbonate of potash, and a small quantity of powdered glass, which are melted together, and when cold are pounded fine. Some of this flux is applied before the work is put in the fire and more while it is being heated. The flux will dissolve any oxide that forms. Uniform distribution of the flux over the surface of the iron will give better results, and may be obtained by using a flexible wire gauze, on each side of which a fluxing agent has been uniformly applied. The gauze is of the same material as the pieces to be welded and is placed between them. During the heating the fluxing agent generally passes off as a gas, while the wire gauze melts and unites with the surfaces.

CLASSIFICATION OF WELDS

14. The different kinds of welds are named according to the manner in which the pieces are put together; they are called *scarf welds*, *butt welds*, *lap welds*, *cleft welds*, or **V** *welds*, *jump welds*, and *fagot welds*. The selection of the weld to use depends on the form of the piece, the forces it is to resist, and the equipment for making the weld.

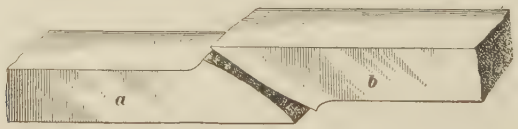

FIG. 8

15. Scarf Welding.— In the scarf weld, the two pieces are *scarfed;* that is, they are thinned down, as shown in the pieces *a* and *b*, Fig. 8. If the iron is of uniform thickness, it is first upset at the point at which the weld is to be made in

order to gain a little in thickness; after this, it is scarfed. To do this, the upset end is thinned down, generally with the peen of the hammer, drawing it out thin at the point and crowding the metal back at the stock by drawing the hammer as shown at *a*, Fig. 9. Sometimes the end of a flat bar, after being upset, is tapered or scarfed by using a fuller, as shown in Fig. 10, which is a quick and effective way. The faces to be welded should be rounded and made higher at the center, as shown at *b*, Fig. 9, so that the pieces first come in contact at this point, in order to squeeze out the flux and impurities as the weld is being closed.

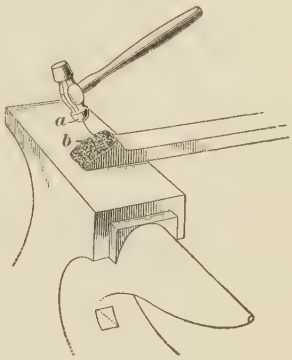

FIG. 9

16. In heating work for welding, careful attention should be given to the fire and the blast. A good body of live coal must be kept below the work. Green coal, which contains gas, tar, and sulphur, should never be thrown on the fire during the heat, because this treatment will spoil the heat. If clean foundry coke can be obtained, a small amount broken up and mixed with forge coke will help to produce a solid fire. Foundry coke is slow in burning, and will deaden the fire, if too much is used. In welding, a moderate blast is employed. A little welding flux is sprinkled on the work directly after scarfing, if a flux is used; this brings the flux over the material before it has time to scale. If some flux is required later, the work is taken out just before

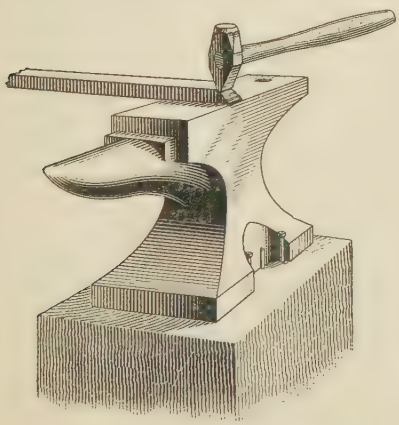
FIG. 10

it reaches a welding heat, the scale is rubbed off, and the flux is applied. The heat should be given time to soak in, and the blast pressure should be increased slowly. When the proper heat is reached the surfaces of the metal will shine and appear as though melted iron were running off them. If the pieces are brought together in the fire, they will adhere. Great care must be taken to heat the work evenly, and the heavier parts should be heated first. The work of welding will be greatly facilitated if the pieces are heated well back of the welding point, whenever possible.

17. The scarfed ends of both pieces having been brought to a welding heat, and fluxed if necessary, the weld is made as follows: The shorter piece is gripped with the tongs in the right hand and the longer piece in the left, the scarfed faces of both being downwards in the fire. Both pieces are drawn out at the same time and each is rapped smartly against the anvil to knock off any coal or other substance that may adhere to the heated surfaces. The shorter piece is brought to the position on the anvil shown at *a*, Fig. 11 (*a*), and is followed with the longer piece, which is brought to the position of the dotted outline *b*. Then, without losing contact between the longer piece and the anvil, the piece *b* is brought down on the piece *a*, as shown in (*b*). If the piece *b* is rested against the edge of the anvil, as indicated by the dotted lines in (*a*), and is rocked to the position indicated by the full lines, the pieces may easily be brought together in their correct relative positions.

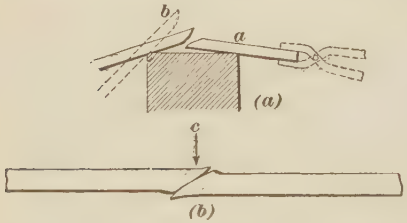

FIG. 11

18. After the piece *b*, Fig. 11 (*a*), has been properly placed on the piece *a*, a slight pressure on it will hold both in position while the tongs are dropped and the right hand relieved so that the hammer may be taken and a light blow delivered in the direction of the arrow *c*, view (*b*). As soon as the pieces

adhere, the ends of the scarf may be brought down by delivering a few light blows on one side, and then the piece turned over and the other side struck in the same manner before it has cooled below the welding heat. If the scarfs are made too long, the surface to be welded is increased and useless labor is involved. All work, after the piece is removed from the fire, should be done as quickly as possible.

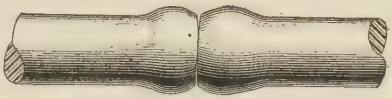

FIG. 12

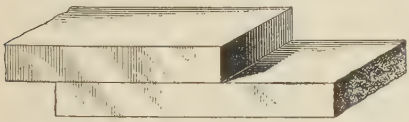

FIG. 13

19. Butt Welding. The butt weld is used for heavy work only. The pieces to be welded are upset at the ends and the end faces are made slightly rounding, or convex, as shown in Fig. 12. The pieces are then put in the fire from opposite sides of the forge, so that their ends face each other, as in the illustration, and they are brought to a welding heat. Flux is added to keep the surfaces clean. When a welding heat is reached, the pieces are driven together while in the fire, until they unite. They are then removed quickly and carefully and finished on the anvil or under the power hammer. The convex ends allow the slag to escape readily when the pieces are driven together in the fire.

20. Lap Welding.—In making a lap weld, the two pieces are laid together face to face, as shown in Fig. 13, and welded. As the faces are not rounded, the hammering is started at the center and gradually carried toward the edges, in order to work out all the slag. If the edges are welded and any slag remains between the faces, the metal will be prevented from uniting in the center.

FIG. 14

21. Cleft Welding.—When a weld is required to stand considerable strain, such as is caused by prying and bending,

or when the weld must be made in the fire, the pieces are generally joined by the cleft weld, shown in Fig. 14. One of the pieces *a* is upset to gain width and thickness, is split open on the end, as shown at *a*, and the two cheeks *c* and *d* are spread apart; the other piece is then scarfed on both edges, as shown at *b*. In welding, the pieces are first hammered on end to get the weld to stick, which may be done in the fire; they are then hammered on the edges to close the weld. The angle of the piece that enters should be smaller than that of the other piece, so that the point *f* will touch and weld first, and the slag be forced out as the sides *c* and *d* close down.

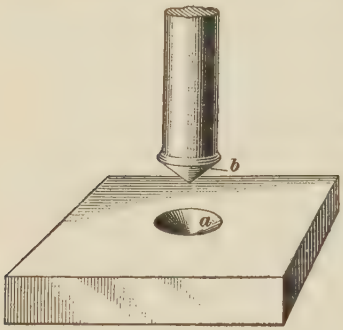

FIG. 15

22. Jump Welding.—The jump weld is really a special form of cleft weld. If a bar is to be welded to a flat plate, a conical depression is made in the plate as shown at *a*, Fig. 15. The bar to be welded is pointed as shown at *b*. The two conical surfaces must be so formed that the parts will come together at the point first, so that any slag will be squeezed out as the piece is driven, or jumped, into its seat. This form of weld is frequently used for quite large work, the bar being driven into place under the steam hammer.

23. Building Up.—It is frequently inconvenient or impracticable to make a forging out of a single piece because of the shape it is to have. In such a case the forging is *built up;* that is, it is made of a number of pieces that are forged to their approximate shapes and then welded together. Fig. 16 shows a built-up forging in which the welds are designated by the letters *a*.

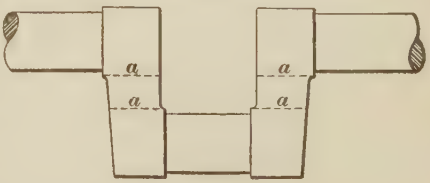

FIG. 16

24. Fagot Welding.—Two or more layers of metal must sometimes be welded together in order to get a piece of stock heavy enough to form an enlarged part, or boss. For this purpose, the piece may be doubled over on itself, or separate pieces may be welded together. The surfaces to be welded must be clean and free from scale. The flux should be put on as soon as the pieces are hot enough to make it fluid, and hammering should start at the center, in order to squeeze out the impurities.

WORK INVOLVING SCARF WELDS

25. Making a Corner Plate.—In order to illustrate some of the applications of the scarf weld, a few simple cases, in addition to those already given, involving the various principles

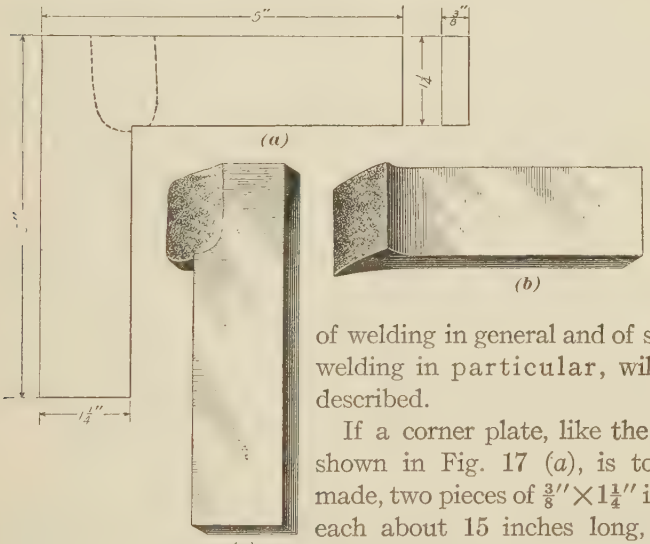

Fig. 17

of welding in general and of scarf welding in particular, will be described.

If a corner plate, like the one shown in Fig. 17 (*a*), is to be made, two pieces of $\frac{3}{8}'' \times 1\frac{1}{4}''$ iron, each about 15 inches long, are heated at one end, one being kept near the edge of the fire so as to heat it more slowly than the other. When hot enough, one is taken from the fire, and the end upset and then scarfed, as shown in (*b*). This is done by striking it, and at the same time drawing the hammer toward the hand, as shown in Fig. 9.

in order to draw the metal that way. The other piece is then taken from the fire, upset at the end, and one edge scarfed as shown in Fig. 17 (*c*).

26. When both pieces are ready, they are put into the fire and raised to a bright-red heat, being turned occasionally to get the heat even. They are then dipped into the flux or the flux is sprinkled over their surfaces and they are returned to the fire and raised to a good white heat on the scarfs. The pieces are turned occasionally to prevent the flux from dropping off. As soon as both pieces approach a welding heat, the blast is turned on stronger in order to raise the final heat rapidly; and if necessary, a little more flux is thrown on the pieces while in the fire. When hot enough, the pieces are brought to the anvil and put together, being held against the edges of the anvil, somewhat as in Fig. 11, care being taken not to touch the cold anvil with the heated portion. When the scarfs are in line, the pieces are brought down flush on the anvil, having the piece in the right hand below the one in the left hand, so that the left-hand piece will be able to hold the other down while the right hand does the hammering. After the pieces stick, they are turned over to bring the other face under the hammer.

27. The form of the scarf should always be such that the centers of the surfaces to be welded come in contact first; the slag will thus be squeezed out as the pieces are hammered together. As soon as the pieces cool to a cherry red, they are reheated and the weld finished. When black hot, both sides of the piece are struck against the horn to make sure that the weld is well made. A good weld will not open on being bent and then straightened. If the weld is good, the corner is tried with a try-square and finished perfectly sharp and square, on the edge of the anvil, as shown in Fig. 17 (*a*). The ends are then cut off, making each arm 5 inches on the long edge. A fillet at the inside corner will add considerably to the strength. If the finished corner is to be more or less than a right angle, the scarf and lap should be made accordingly.

28. Making a T Plate.—A T plate like the one shown in Fig. 18 (*a*) can be made in nearly the same way as the corner

plate. The crosspiece *a* is scarfed as shown in (*b*), and the piece *b* is upset and scarfed on one end, as in the corner plate.

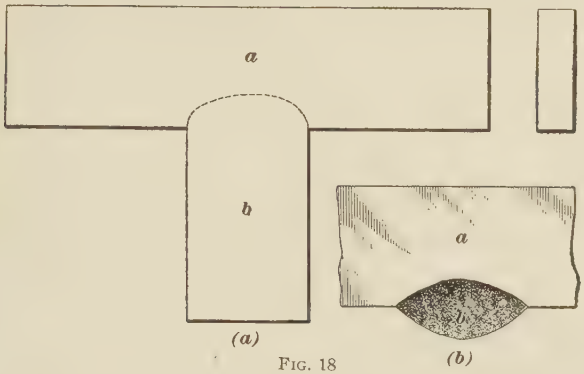

FIG. 18

When both pieces have been prepared, they are heated, fluxed, and welded, as described in the construction of the corner plate.

29. Making a Band Ring.—In making a band ring, like the one shown in Fig. 19 (*a*), a piece of $\frac{3}{8}'' \times 1\frac{1}{4}''$ iron, 12 inches long, is upset at both ends. The ends are scarfed on opposite

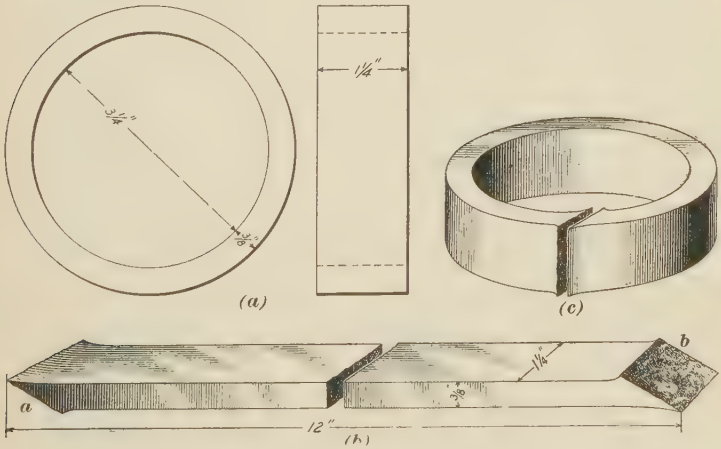

FIG. 19

sides, as shown at *a* and *b*, view (*b*), and the iron is bent into the form of the desired ring. To do this, the iron is heated and

then laid across the horn of the anvil and projecting beyond it. The projecting end is hammered and bent around, as shown

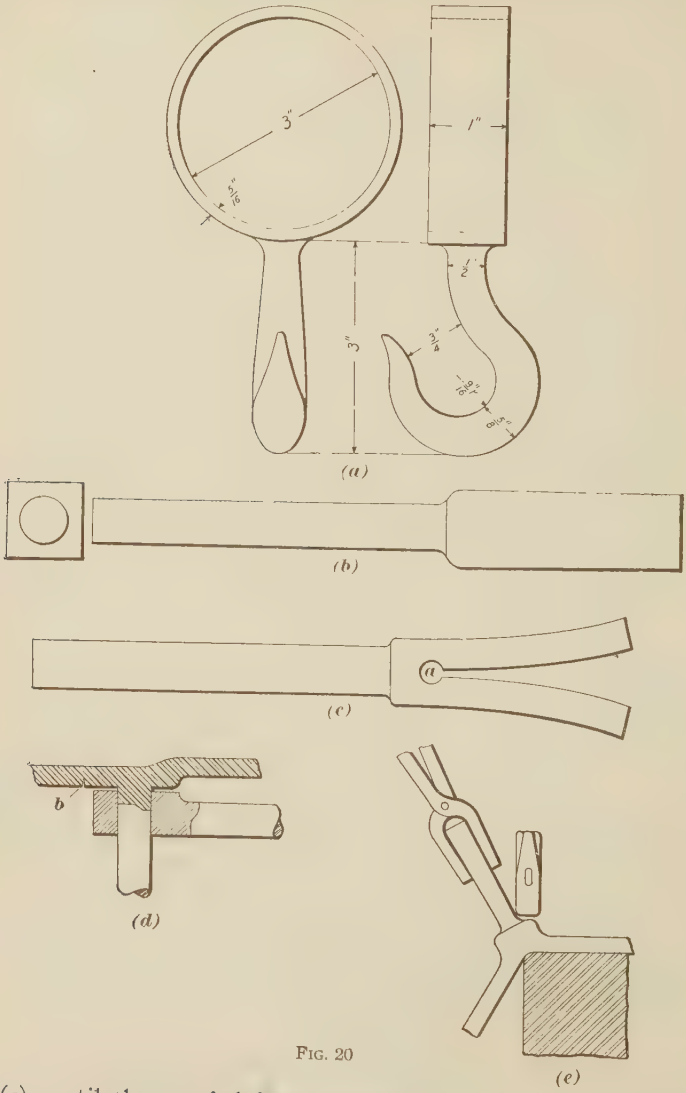

Fig. 20

in (*c*), until the scarfed faces are in position for welding, but about $\frac{1}{4}$ inch apart. The ends are next heated and fluxed, and

then raised to a welding heat. To weld the ring, it is brought to the anvil and slipped over the horn, with the scarfed ends on the upper side of the horn. A few rapid blows with the hammer will make the weld, after which the ring is trued up so as to make it round and to make the iron of the required width and thickness throughout. This is done over the horn of the anvil.

30. Making a Ring Hook.—A ring hook of the form shown in Fig. 20 (*a*) may be scarf-welded. Its construction also shows a method of splitting stock for branch pieces that is valuable in smithing operations. On a piece of iron of good quality, such as Norway iron, $\frac{7}{8}$ inch square and 5 inches long,

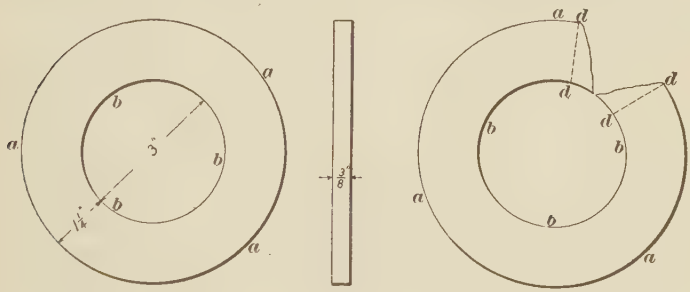

FIG. 21

a length of 2 inches is marked off from one end with a center punch and this piece is drawn out to 5 inches, leaving the stock of the form shown in (*b*). Next, a hole *a*, view (*c*), is made with a punch, the stock split out to the end, and the branches bent apart, as shown. The shank is then placed in a heading tool and the branches bent out, as illustrated in (*d*). During this part of the work, great care must be taken to prevent cracks from starting in the corners, as shown at *b*. When the iron has closed around cracks started in this way the piece is liable to be dangerously weak where they occur. They may be avoided by removing the piece from the heading tool when the branches have been partially bent out, placing it over the round corner of the anvil, and using a large fuller or a set hammer, as indicated in (*e*). The branches are drawn out to the

proper dimensions, scarfed, bent to the ring form, and welded as in the case of the band ring. The piece is held in the tongs by the ring while the hook is being shaped. The finished piece should be sound, show no scarf or weld marks, and agree with the dimensions on the drawing.

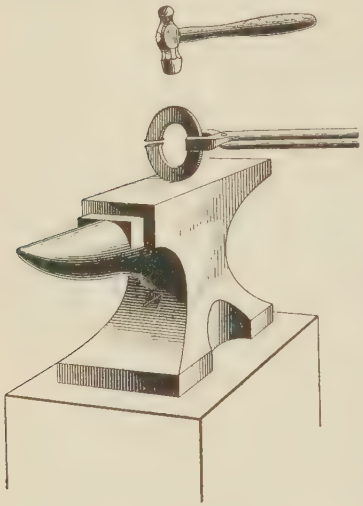

FIG. 22

31. Making a Flat Ring. In making a flat ring, as shown in Fig. 21 (*a*), a piece of $\frac{3}{8}'' \times 1\frac{1}{4}''$ flat iron 14 inches long is cut off and heated, and the end farthest from the tongs is bent edgewise over the horn of the anvil. As the circumference of the outside circle *a a a* of the ring is considerably greater than the circumference of the inner circle *b b b*, the iron will be upset along the inner edge and stretched along the outer edge by the bending. This will make the iron thicker than $\frac{3}{8}$ inch at the inner edge and thinner along the outer; the iron will also buckle and twist when being bent. By hammering it flat on the anvil, using the flatter if desired, the iron can be brought back to an even thickness; however, it should not be allowed to get far out of size, and its width and thickness should be frequently tried with the calipers. When bent, the iron will have the form shown in (*b*); the corners are then cut off, as indicated by the dotted lines *d d*, the ends scarfed and the iron bent on the anvil, as shown in Fig. 22, until the scarfs overlap, their inner surfaces remaining about $\frac{1}{4}$ inch apart, as illustrated in Fig. 23. The heat is then raised, the weld made, and the ring finished with the hammer.

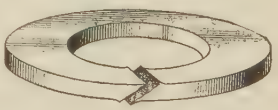

FIG. 23

32. Making a Chain.—A chain like that shown in Fig. 24 is made from $\frac{1}{4}$-inch round iron that is cut into suitable lengths,

bent, scarfed, and welded into links that are afterwards joined. Each oblong link is made from a piece of stock $3\frac{1}{2}$ inches long. This piece is bent at the middle, over the horn of the anvil

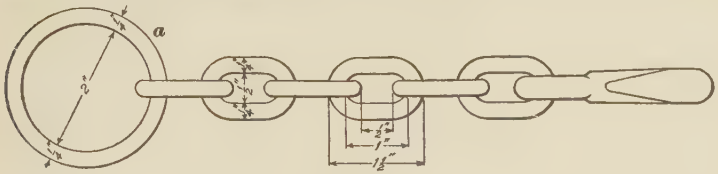

Fig. 24

or around a pin of suitable size, bringing the ends parallel and of the same length. These ends are next scarfed, one on one side and the other on the opposite side, so that, when the ends are bent inwards, the scarfs face each other. These ends, after being bent so that the scarfs overlap, are brought to a welding heat, fluxed, and welded on the face of the anvil. The ring is finished on the horn. The weld is usually the thickest part of the link and is at the point where the wear is greatest. In making a long chain, two separate links are made and welded, and a third link is used to join them, forming a section of three links. Two such sections are slipped on a split link and the latter is closed and welded, thus joining the sections. This operation is repeated until a chain of the desired length is obtained

33. Making a Pair of Tongs.—To make a pair of blacksmith's tongs for holding flat iron, such as is shown in Fig. 25, a bar of $\frac{3}{4}$-inch square iron, not more than 2 feet long, is marked at 2 inches from the end and heated. When hot, the marked end is flattened to a thickness of $\frac{7}{16}$ inch, leaving the shoulder,

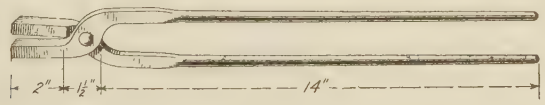

Fig. 25

as shown at *a*, Fig. 26 (*a*), on one side. This may be done by holding the iron so that the marked edge is on the edge of the anvil and by flattening the end with the hammer. The piece is

again heated and placed on the anvil, as in (*b*), and flattened for about 3 inches in length. It is then cut from the bar and the other end *c g* of the piece is offset, as shown at *c*, view (*c*), and flattened for about 3 inches in length. The end *g d* is then drawn down to $\frac{1}{2}$ inch round, as shown. The end *d* may be left a little larger than $\frac{1}{2}$ inch, and then scarfed for welding. A duplicate piece is then made and a $\frac{1}{2}$-inch round rod 12 inches long is welded to each to form the handles. A $\frac{3}{8}$-inch hole is then punched through one of the pieces, as shown at *b*, view (*d*). The two parts of the tongs are now held together and the hole marked in the second piece by punching it through the hole already made. The first piece is then laid aside and the hole punched through the other one.

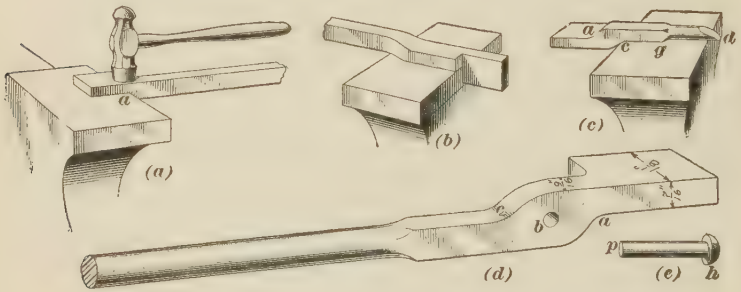

Fig. 26

34. The pin or rivet, shown in Fig. 26 (*e*), that is to hold the two parts together, is made by upsetting a $\frac{3}{8}$-inch rod at one end and forming it into a head. It is then cut from the bar, making it the proper length, and tried in the tongs to make sure that it fits. It is then put into the fire and heated on the end *p*. When hot the finished head *h* is cooled by being dipped in water, but the end *p* is left hot. The pin is then replaced in the fire and heated on the end. When hot, it is put through the two holes and the tongs finished by riveting the end of the pin. It frequently happens that the rivet bends in the holes; this makes the tongs tight, but the jaws will not stay parallel. In such a case the rivet must be driven out while it is still hot and another one made.

35. The fuller may be used to good advantage in making the tongs. The bar having been cut down part way with the hot cutter, the material may be worked out to approximately the correct form with the fuller. Sometimes, it is well to take a heat over the work; that is, to go over the piece, when it is at a white heat, with a light hand hammer. In this way, the fibers that have become separated are rewelded and the forging improved. Since the weakest places of the tongs are at the offsets and corners, the largest possible fillets should be at these points. The fillets may prevent the tongs from working easily; but if the tongs are heated to a red heat after riveting and are worked back and forth, the joints will usually loosen. The flat space around the rivet hole should be as large as possible, to increase the strength of the tongs.

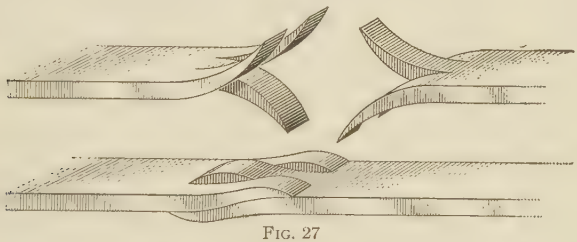

FIG. 27

In making tongs, the parts should be inspected very closely before putting them together. A good way to detect flaws and defects is to heat the suspected part to a dull red; this will show all defects, such as cracks, seams, poor welds, etc., which often occur in the welds, angles, offsets in the jaws, and the metal near the punched holes. If the defects cannot be remedied, a new part must be made.

36. Welding a Spring.—Great care is necessary in welding a spring, because the steel beyond the weld is apt to be overheated, causing the spring to break later at that point. Different forms of welds are used, with equal success, though some are more difficult to make than others. A common way of welding a spring is shown in Fig. 27. Each end is split into three tongues and the middle tongue is bent away from the two outer ones, so that, when the two pieces are brought together,

they will fit, as shown in the illustration. As the scarfs in this weld are long and thin, the welding must be done rapidly, or the anvil will cool the pieces and cause a poor weld. The long lap of the scarfs is a disadvantage, as greater care is required to insure good results. If desired, the scarf weld shown in Fig. 11 may be used for joining springs. Each piece is upset and then scarfed, after which the pieces are put in the fire with the scarfs facing upwards. As soon as the flux melts and adheres to the scarfed faces, they are turned over and the ends are brought to a welding heat. The weld should be made at one heat, as there is danger of overheating the parts on each side of the weld while getting a second heat on the upset part. It is a good plan to roughen the scarfs, so as to prevent them from slipping.

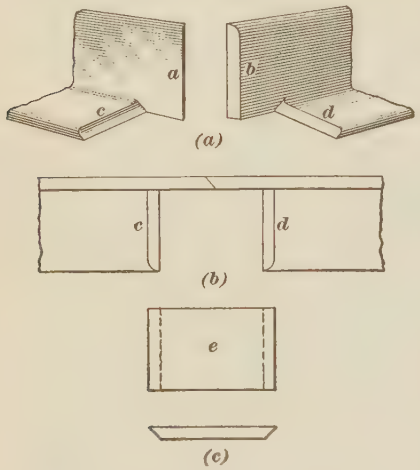

FIG. 28

37. Welding Angle Iron.— Two pieces of angle iron may be welded together, end to end, by using the scarf weld. The ends are scarfed in the usual way, without upsetting, and the heel or corner of the angle is welded first. The welding of the sides is then completed, though it is the more difficult part of the operation, as the sides frequently do not weld perfectly. A better way of doing this work is to cut away a piece from corresponding sides, as shown in Fig. 28 (*a*), leaving the ends *a* and *b* projecting. These are now scarfed on opposite sides, heated, fluxed, and welded. The pieces will then be joined, as in (*b*), with a gap between the ends *c* and *d*. These ends are scarfed, and a piece of metal *e*, shown in (*c*), of the same width and thickness as the angle iron, is scarfed to correspond and is welded in place between the ends *c* and *d*.

WORK INVOLVING BUTT WELDS

38. Knuckle-Joint Strap.—To make a knuckle-joint strap, shown in Fig. 29 (*a*), a short bar of stock is taken, slightly wider than one-half the width *a* of the strap, and of the thickness shown at *b*. The notch *c*, view (*b*), is made with the fuller and the end of the bar drawn to the form shown by the dotted lines. Next, this end of the bar is cut off at such a place as will give the piece shown in (*c*), and the face hollowed as shown at *d*. A second piece of the same form is then made, except that the face *d* is convex instead of concave. There will now be two pieces, as shown in (*d*), to be welded together, the

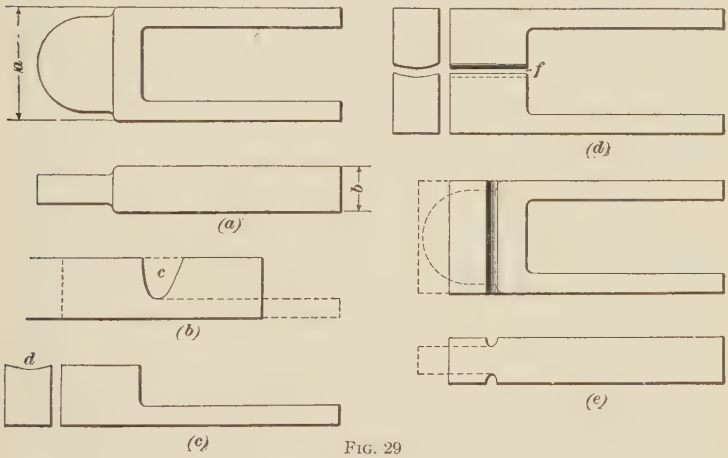

FIG. 29

excess of width having been given, that they might upset slightly at *f* during this operation.

39. To weld them together, the two pieces are heated at the same time. When at a welding heat, the pieces are placed on the anvil in the relative positions shown in Fig. 29 (*d*), and the weld made with light blows of sledge hammers; or, they may be placed between the dies of a power hammer and welded with light blows, care being taken that the blows do not draw the sides too close to each other. Too heavy blows are liable, also, to spread the edges of the weld and weaken it. The

piece should be turned on its side, after the faces are welded, and the sides closed before the welding heat is lost. It must be remembered that the weld is due to the fluid condition of the metal at the surfaces that are joined, and the blows delivered should have only force enough to bring the surfaces entirely together. After the weld is made, the grooves shown in (*e*) are made with the fuller, and the end drawn out as illustrated by the dotted lines. The end is then cut to the curved form shown in (*a*) by the use of a hot cutter, and this end finished on the anvil.

MISCELLANEOUS EXAMPLES OF WELDING

40. Welding On Bolt Heads and Collars.—A ring may be welded to the end of a rod to form a head, or to the middle of a rod to form a collar. The welding operation in each case is the same. The first step is to bend the ring to shape and size from a piece of round or square stock. The ring thus made should not be welded but should be a split ring; that is, its ends should be about $\frac{1}{16}$ inch apart and the inside diameter should be just great enough to enable the ring to be slipped over the rod to which it is to be welded. The rod is first heated to a red heat; then the split ring is placed in the fire and both the ring and the rod are brought to a welding heat. When they have been withdrawn from the fire, the rod is quickly thrust into the ring and the first blow of the hammer is struck so as to close the gap in the ring, which is thus drawn tightly around the rod and can be welded firmly in place. Bolt heads made in this way are usually larger than the standard sizes formed by the upsetting operation.

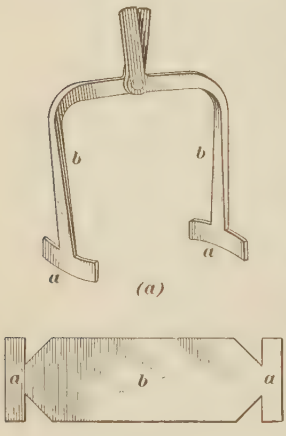

FIG. 30

41. Crucible Tongs.—The jaws of a pair of tongs for lifting crucibles are shown in Fig. 30 (*a*). It would be possible

to make the jaws by welding the fingers *a* to the arms *b*; but as the tongs are subjected to a high temperature when handling crucibles, there is danger that a weld will be weakened and fail. It is better, therefore, to forge the arm and its fingers from one piece. Both jaws may be made from a piece of flat stock like that shown in (*b*). The sides are nicked deeply, at such a distance from the ends that the end parts *a* will be of the proper width to form the claws or fingers of the tongs. The central part *b* is then drawn down by hammering to the size of the arms of the jaws, after which it is cut in two at the middle. Each piece is then bent to form one jaw.

42. Ladle Shank.—In the foundry, ladles are lifted and carried by ladle shanks. A ladle shank consists of a circular

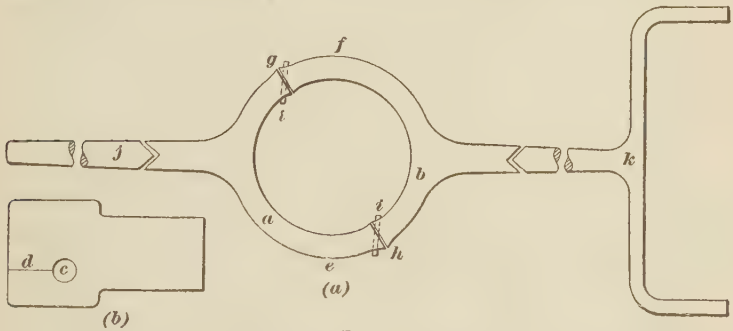

FIG. 31

ring in which the ladle fits, and to which are welded handles by means of which the whole may be carried and tilted. The supporting ring is made in two parts *a* and *b*, Fig. 31 (*a*), that are afterwards welded together. Each part is formed from a piece of flat stock like that shown in (*b*). A hole *c* is punched through the stock, and the piece is split, as at *d*, to one side of the center line. The work is then bent and drawn to the shape of the piece *a*, view (*a*). The reason for splitting the stock off the center line is to make the arms of the piece *a* unequal. If they were made of the same length, the welds would come at the points *e* and *f*, where the bending strain is greatest, instead of at *g* and *h*. The piece *b* is made in the same way as the piece *a*, and the ends of the forks are scarfed as shown at *g* and *h*. They are clamped

and drilled so that iron rivets *i* can be put through to hold the pieces in their correct relative positions during welding. The parts at *g* and *h* are then heated and welded, after which the handles *j* and *k* are attached by cleft welds.

43. Open-End Wrench. There are several ways of forging an open-end wrench. One method is to split a piece of flat stock as shown in Fig. 32 (*a*), spread the fork, and bring it to the shape shown in (*b*). The ends *a* are next folded in toward the center *b*, on the same side, as shown by the dotted lines, and are welded down, thus forming a thick, heavy end that is still T-shaped. The branches are next bent over as in (*c*), to form the jaws of the wrench, and the inside faces are squared by filing, to fit the nut for which the wrench is intended.

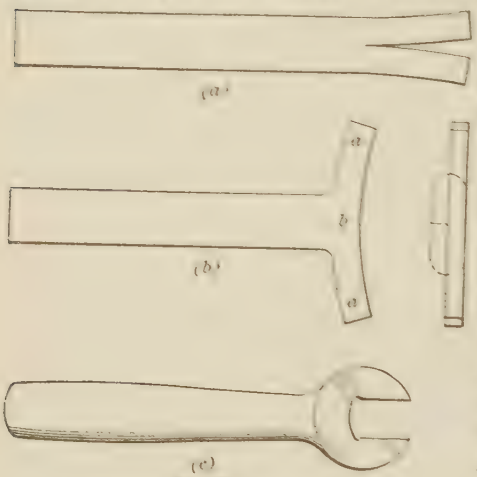

FIG. 32

Another method of making an open-end wrench is shown in Fig. 33. A piece of flat stock of the required thickness is heated and fullered near the ends as shown in (*a*). The central part is drawn out to the size and length of the handle, as in (*b*), and the ends are forged to a T shape, as shown in (*c*). The branches of each T are next bent over, as in (*d*), to form the jaws of the wrench. One branch should be drawn around farther than the other, so that, when the opening is squared, as in (*e*), it will stand at an angle to the center line of the handle. The wrench illustrated is double-ended, but the same method may be used in making a single-ended wrench.

44. Rocker-Arm From One Piece. To make a rocker-arm from one piece, round stock is taken that is large enough in diameter to give, when flattened, the dimension *a*, Fig. 34 (*a*),

and drawn to the form shown in (*b*). This will require great care, for there is danger that the dimension *c* may be made too great, or, if this is right, that the dimension *b* may be too small. Enough of one end is flattened to form the arm, and drawn to the form shown in (*c*). The dimension *d* is made to correspond to *d* in view (*a*). This piece is flattened with the hammer, the side toward which the stock is drawn being made as true and flat as possible from the shoulder to the end, and the recess at *d* formed by the use of the fuller. This leaves the stock *f* on the end, from which to form the boss. Next, the piece is clamped firmly near one shoulder and the flattened portion bent down, making the whole piece of the form shown in (*d*), by clamping the piece between the hammer dies and driving down the arm with sledge hammers. The boss is rounded as shown at *g*, view (*e*), by first shaping it to the form shown by the dotted lines at *g*, view (*d*), and then rounding it to form the boss. The portion outside the shoulder on the other end of the piece is treated in the same manner, or both ends may be flattened and notched first, and then bent. Rocker-arms are also forged by welding both arms to the shaft.

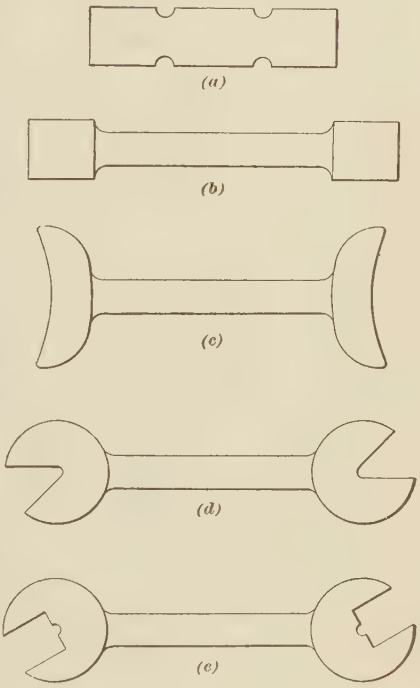

FIG. 33

45. Rocker-Arm With Welded Shoulder.—When it is not considered desirable to use stock that is large enough to form a shoulder of the required size, the shoulder should be

made in the manner indicated in Fig. 34 (*f*). The rocker-arm is made from the stock at hand, leaving it too small at the shoulders and on the arms near the shoulders. A separate piece of stock is drawn to the form shown at *i*, and bent to fit closely around the shoulder that has been formed, as shown by the dotted lines. A welding heat is then taken on one

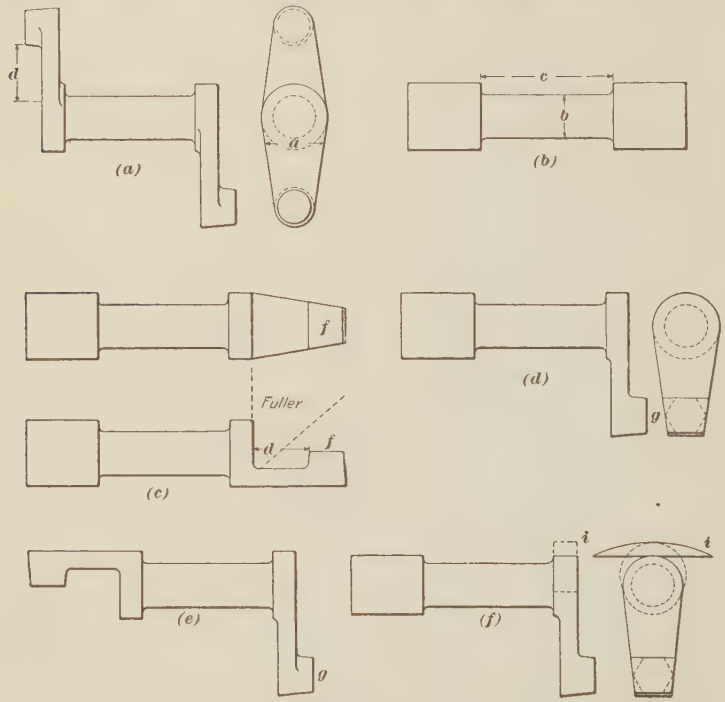

Fig. 34

shoulder, and that side is welded; this operation is repeated on the other side. After both shoulders have been treated in this way, the whole piece is gone over carefully and dressed to shape.

46. Locomotive Reverse Shaft.—The method of forging a locomotive reverse shaft varies in different shops, but a good way of doing it is shown in Figs. 35 and 36. The shaft is first heated at *a*, where one of the arms is to be welded, and enlarged by upsetting, which is accomplished by swinging a heavy

suspended steel ram *b*, Fig. 37, against its end, the shaft being supported in a special fixture or anvil *c*, Fig. 35, made for the purpose. Similar heats are taken at other points where arms are to be welded. The arms are previously forged, usually under a drop hammer. The end of each arm is split, and each end is drawn out, as shown at *e* and *f*, Fig. 36 (*b*). View (*c*) also illustrates some of the details of the form of the arms and shaft before welding. The small arm *a*, view (*a*), is first welded to the shaft, after which one of the link-supporting arms *d* is welded on.

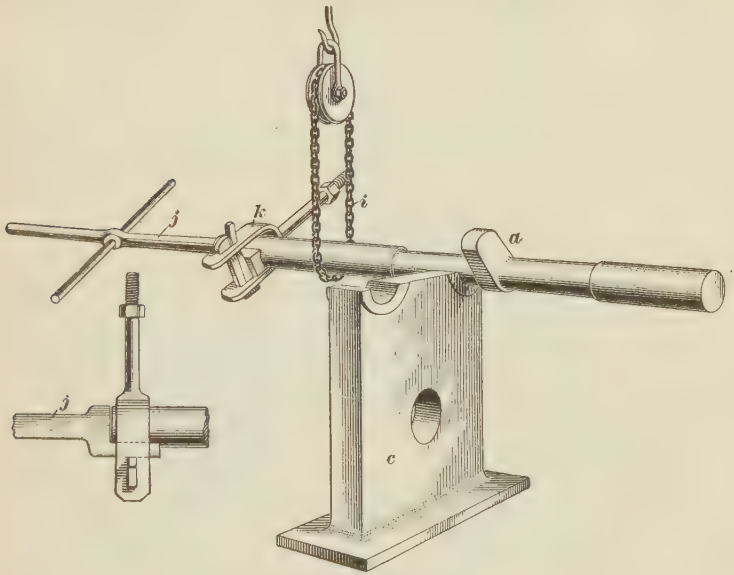

FIG. 35

47. The shaft is heated in one fire and the end of the arm in another; when they are both at the proper heat, they are brought out, the shaft is dropped into the crotch of the special support *c*, Fig. 37, and the arm placed on it. A few sharp blows on the upper end of the arm commence the weld at the center, and blows at *e* and *f*, Fig. 36 (*b*), complete it, a swage being used to finish the fillets about the end of the arm. The other arm *h*, view (*a*), is then welded on in the same way. The long arm *g* on the end of the shaft is sometimes made by first welding on a short piece, after which the shaft is taken to the machine

shop, machined, then returned to the smith shop, and the remainder of this long arm welded on, thus overcoming the difficulty of turning the shaft in the lathe with the long arm on it.

48. During the welding the weight of the shaft is partly supported by the chain *i*, Fig. 35, hanging from a chain block on a swinging crane. The shaft is handled by the fixture *j*,

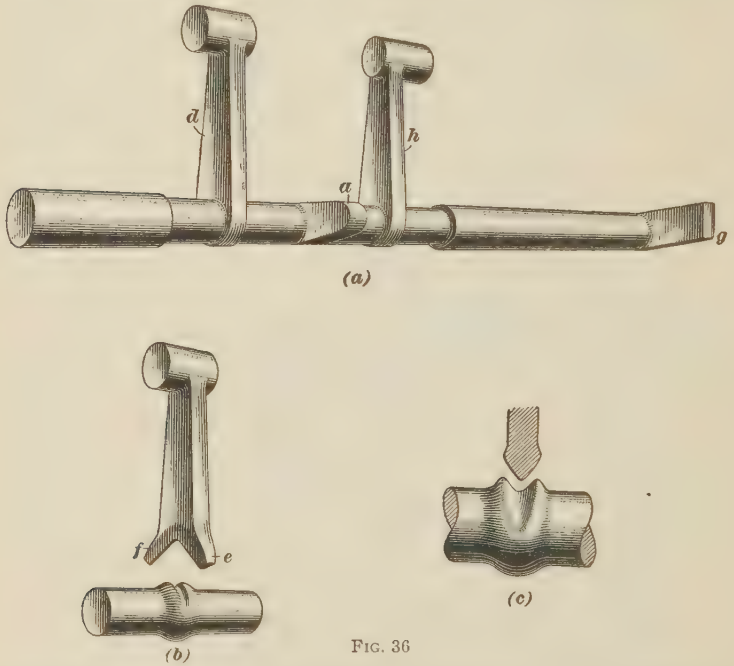

Fig. 36

which is fastened to it by means of a clamp *k* provided with a gib and key. The end of the clamp *k* has a thread and nut for the purpose of attaching weights to counterbalance the arms *d* and *h*, Fig. 36. The main forge is at *l*, Fig. 37. The forge in which the arms are heated is located at *m*. A cast-iron plate *n*, about 4 feet by $7\frac{1}{2}$ feet in size, planed on the top and the edges, strongly ribbed on the bottom, and provided at one side with a pair of centers, adjustable lengthwise in a groove, is used to test the straightness of the shaft. There is a space of 3 or 4 feet between the fixture *c* and the plate *n*.

49. Locomotive Valve Yoke.—Of the several methods of making a locomotive valve yoke, one of the best is to use a piece of square hammered iron, as indicated by the dotted lines in Fig. 38, and draw one end as shown at *a*. The other end is split, opened out, and each end drawn out as shown at *b* and *c*, after which the two ends are split and bent down as illustrated at *d* and *e*. Another piece of iron is prepared

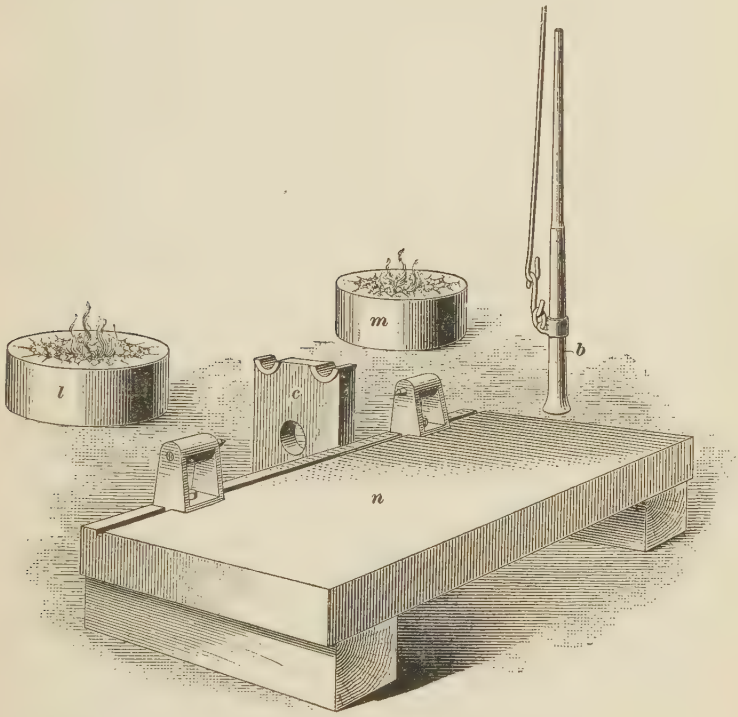

FIG. 37

of the proper size and length and bent as at *f*, with its ends properly scarfed for welding. First one side is welded and then the other, when it only remains to give the yoke the necessary finish. The clamp *g* is used to hold the parts in place while making the first weld at *e*.

50. Wrought-Iron Rudder Frame.—Many rudder frames of late years have been cast in open-hearth steel, in one

piece; but owing to the possibility of hidden blowholes, or invisible cracks in the corners, a wrought-iron frame is sometimes preferred. Fig. 39 shows such a frame in which it was necessary to make nineteen welds, the location and order of which are shown by the figures, the dotted lines indicating the character of each weld. Number *19* was made by welding in a diamond-shaped piece, or *glut*, which has the fiber of the iron lengthwise in the finished work.

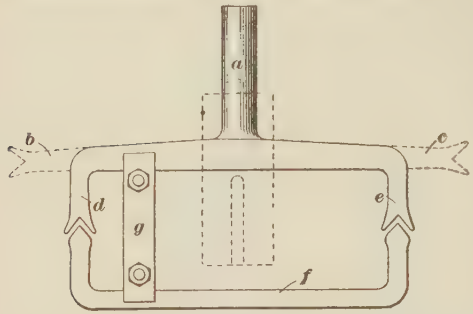

FIG. 38

The main piece *a* in this case is 23 feet long. Eight inches of the upper end is square, below which it is turned 9 inches in diameter for a length of 6 feet. A pivot *c* is also turned at the lower end. The part of the frame *d* to which the arms are welded is square on that side and half round on the back, as shown in section at *e*. The arms, where they are joined to *d*, are from 3 to 4 inches by $9\frac{1}{4}$ inches. At the outer end *f* they are 3 inches by $9\frac{1}{4}$ inches, and the part of the frame at *g* is the same size.

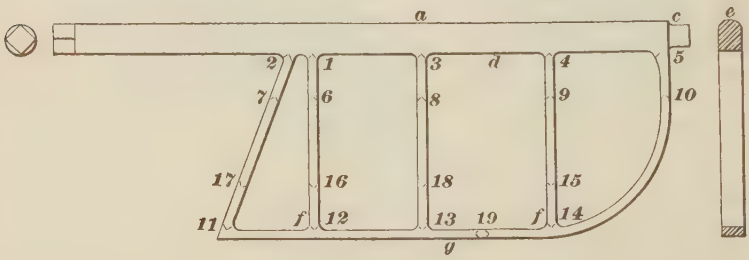

FIG. 39

51. Most of the welds are **V**-shaped, or cleft welds, but occasionally a double-cleft weld is used, into which a diamond-shaped piece is welded, in order to obtain the correct dimensions. Most of the welding is done without taking the frame

out of the fire. The frame, laid on a flat-topped forge, is temporarily enclosed in firebricks at the point to be welded; the fire is then built under and around the point, the top of the brickwork being covered with several sections made up of an iron frame filled with firebricks and provided with a bail, or eyebolt, for lifting the section to replenish the fuel or remove the work. Sometimes a chain fitted with a turnbuckle is so arranged on either side of the frame as to enable the parts that are to be welded to be drawn together.

52. Two steel ramming bars are provided, each about 9 feet long and $1\frac{3}{4}$ inches in diameter, except at the working end, where they are $2\frac{1}{2}$ inches in diameter and slightly rounded. When the welding heat is reached, the turnbuckles are quickly tightened, the ramming bars introduced through either end of the furnace, and the scarf of the weld vigorously pounded down. The top covers of the furnace are then removed and three men with sledges finish the upper edge of the weld. The piece is then lifted from the fire and placed on the anvil and the entire weld gone over with sledges, three men striking at the rate of about 36 blows each, or 108 blows a minute, on the work. Care is usually taken to have a little surplus stock at the weld, which is then trimmed off with a hot cutter.

53. Welding Pipe.—An open fire with an overhead hood is well adapted to pipe welding, which may be done in a forge fire in several ways. In the case of extra heavy iron or mild-steel pipe welded together in lengths varying from two pipe lengths to 300 or 400 feet, as used for refrigerator coils and sometimes for steam coils for heating liquids, the pipe may be prepared by reaming it out at one end to a taper of about 60°, the other end being given an outside taper to match. This operation can be done on a turret machine or, with suitable dies, on a bolt cutter. Long lengths of pipe, while being heated, are usually supported by a wooden trough or box. The ends of the pieces of pipe, with inside and outside taper, are placed in the fire and brought to a welding heat, using a little sand or other flux if required. The ends of the pipe are brought together in the fire, and two or three sharp blows are given on

the cold end of one pipe by the helper, the smith meantime holding the other pipe. The weld is started by the blows on the end of the pipe, which is quickly drawn through the fire, bringing the weld into a bottom swage or on to an anvil located near the fire and directly under the pipe. The blacksmith applies a top swage, while the helper strikes light quick blows on the swage with a very light sledge hammer, the blacksmith turning the pipe meanwhile. The welding must be very quickly done, as pipe cools more quickly than solid iron. A few passes of a coarse file will remove the scale, and the pipe is then moved endwise in the trough for the next weld.

54. Welding Bar Iron to Pipe.—To give lightness, the handles of long tools are often made of pipe, which is welded on. An example of this class of tools is the slice bar used by the fireman of a stationary boiler to clean the fire. The solid iron or steel end of the tool is upset at its shank, and the pipe that is to form the handle is split for a distance of 3 or 4 inches from the end. The solid shank is first placed in the fire and well heated. Then the split end of the pipe is put in, so that both pieces will reach a welding heat at the same time. The shank is inserted in the split end of the pipe and the two are driven together before being removed from the fire. The weld is closed and finished on a bottom swage.

55. Welding Boiler Tubes.—The ends of boiler tubes often give out while the main parts are still in good condition. To avoid the expense of wholly new tubes, new ends are welded on the old tubes. The worn-out ends are first cut off squarely and the ends of the remainder of the old tube are given a slight taper. Pieces of new tube, known as safe ends, are cut slightly longer than the old pieces that were cut off. Each safe end is scarfed at one end, over the horn of the anvil, and is thus flared enough to allow the tapered end of the old tube to enter it. The ends of the safe end and of the old tube are placed in the fire and brought to a red heat. The safe end is then withdrawn and set on the anvil with the flared end up and the helper drops the tapered end of the old tube in, jarring it down until the two overlap $\frac{1}{2}$ or $\frac{5}{8}$ inch. The smith immediately

closes the joint all around by hammering down the scarf with a light hammer. The closing should be done quickly, as a tube loses its heat much more rapidly than does a solid bar.

56. After the scarf has been closed down, so that no dirt can get into the joint, the piece is replaced in the fire and brought to a welding heat. A mandrel of suitable size is then inserted into the safe end and the weld is hammered down and finished by using top and bottom swages. The swages should have chamfered edges, so that the tube will not be caught and pinched.

The safe end and the old tube may be joined in the fire before the final welding. In that case, both are brought to a welding heat, as before, and the tapered end is inserted into the safe end. The helper strikes the safe end and drives it over the old tube, at the same time keeping it in line with the tube. The smith, using a light hammer with an iron handle, welds the scarf all around, while the pieces are still in the fire. The final hammering and completion of the weld are done as before, with mandrel and swages.

TOOL DRESSING

TOOL STEELS

METHOD OF MANUFACTURE

1. High-carbon steels and high-speed steels are known as **tool steels.** The **high-carbon steels** are compounds of iron and carbon, containing from .60 to 1.50 per cent. of carbon. They differ from one another principally in the amount of carbon they contain, and their most valuable property is that, by proper heat treatment, they may be made very hard. The **high-speed steels** contain, in addition to the iron and carbon, one or more of the following metals: chromium, tungsten, molybdenum, and vanadium. These steels possess an advantage over the high-carbon steels in that tools made of them will cut at much higher speeds than is possible with tools made of carbon steels, as high-speed steels have the property, known as **red hardness,** of retaining their hardness when heated to a red heat.

2. The best grade of tool steel is made by what is known as the crucible process, and is called crucible steel. **Crucible steel,** also called **cast steel,** is made by melting a combination of suitable materials in a crucible, and then casting the charge into an ingot that is reheated and rolled into bars. One method of making crucible steel is to pack wrought iron, which may be broken into small pieces, and some material that contains the desired amount of carbon into crucibles, and then melt it. These crucibles are about 2 feet high and 10 inches in

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diameter and are capable of withstanding very high temperatures. The melting furnaces are of various forms, but all are either lined with or made entirely of refractory material. These furnaces are frequently rectangular in form, and large enough to hold two crucibles with the necessary fuel for melting their charges. They are arranged side by side in a row and connected with a common flue; their tops are usually on a level with the floor, while the ash-pits are reached from a pit extending along the front of the row.

3. Sometimes manganese and material for a flux are added to the charge in the crucibles, after which the crucibles are carefully covered with air-tight lids made of the same material as the crucibles. After the charge is fused, it is cast into an ingot, which is more uniform in structure than the wrought iron from which it was made. This ingot is reheated and worked under the hammer, then rolled or hammered into bars and placed on the market; this working greatly improves the quality of the metal.

The product of this method of working was the first to be called crucible or cast steel, but now the term is applied also to the product obtained by fusing together in sealed crucibles wrought iron and carbon, to which there are added tungsten, chromium, molybdenum, or vanadium, and a flux, and casting them into an ingot that is treated in the same manner as that just described.

4. The material called cast steel, the use of the term being herein confined to crucible tool steel, must be carefully distinguished from the material represented by the term *steel casting*. The latter term denotes a material made by a different process and is altogether different from cast steel.

Many of the modern furnaces are fired by gas or crude oil. The contents of the crucibles are sometimes poured into a large ladle, which mixes the charge and insures a more uniform grade of steel. The contents of this large ladle are then poured into ingot molds and these ingots are subsequently worked down under hammers or with rolls. The best tool steel is worked down entirely under hammers.

TEMPER AND TREATMENT OF TOOL STEEL

TEMPER

5. The steel maker uses the word *temper* to indicate the amount of carbon in the steel; thus, steel of high temper is steel containing a high percentage of carbon; steel of low temper is steel containing little carbon; steel containing amounts of carbon between these is said to be of medium temper. This term should not be confused with the act of tempering, which is an operation for reducing the hardness of steel to such a degree as to adapt it for doing the particular kind of work required. The temper of steel is often indicated by saying that it has a certain number of **points of carbon**, a point being .01 per cent.; thus, when it is said that a piece of steel contains ten points of carbon, it has ten one-hundredths per cent., or one-tenth of 1 per cent., of carbon, which is usually written .10 carbon, and the steel is known as point 10 carbon steel, or 10 point carbon steel. A .10 carbon steel may also be indicated thus, .1 per cent. carbon steel.

6. Seebohm gives the following list of useful tempers for tool steel:

Razor temper, 1.5 carbon. Steel of this temper requires very skilful manipulation, as it is easily burned by being overheated; when used for turning chilled rolls, it will do much more work than ordinary tool steel.

Saw-file temper, 1.40 carbon. Steel of this temper requires very careful treatment; although it will stand a higher degree of heat than the preceding temper, it should not be heated beyond a cherry red.

Tool temper, 1.25 carbon. Steel of this temper is most useful for drills and lathe and planer tools when they are to be used by the average workman; by careful and skilful manipulation, it is possible to weld steel of this temper.

Spindle temper, 1.10 carbon. Steel of this temper is good for very large turning tools, circular cutters, mill picks, taps, screw-thread dies, and the like; it requires much care in welding.

Chisel temper, 1.00 carbon. Steel of this temper is very useful for a great variety of tools. It welds easily, is tough when unhardened, and may be hardened at a low heat; it is well adapted for tools that must have a hard cutting edge backed by unhardened metal that will transmit the blow of the hammer without breaking, as in cold chisels.

Set temper, .80 carbon. Steel of this temper is well adapted for tools, such as cold sets, having an unhardened part that must hold up under the severe blows of a hammer; it may easily be welded by a smith accustomed to working tool steel.

Die temper, .75 carbon. Steel of this temper is suitable for tools that must have a hardened surface and be able to withstand great pressure, as dies for drop hammers, or for pressing or cupping sheet metal into boiler heads and allied forms; it is easily welded.

7. The percentages of carbon in the steels suitable for different classes of work under average conditions are as follows:

.50 carbon for hot work, battering tools, hammers, etc.

.60 to .70 carbon for dull-edged tools.

.70 to .80 carbon for cold sets and hand chisels.

.80 to 1.00 carbon for chisels, drills, dies, axes, knives, etc.

1.00 to 1.20 carbon for axes, knives, large lathe tools, large drills, and dies. If used for drills and dies, great care is required in tempering.

1.20 to 1.70 carbon for lathe tools, small drills, etc.

.90 to 1.00 carbon is the best steel for general work.

TREATMENT OF TOOL STEEL

8. Distinguishing Iron and Steel.—The smith is often called on to pick out a piece of a certain kind of steel from a pile containing iron, low-carbon steel, high-carbon steel, and special steels. Formerly, the only test was to pick up a piece and strike it with a hammer; if it sounded dead it was wrought iron, if it rang it was steel. This did very well when only one grade of steel was used in a given establishment, but now, when many grades are used, it is much more difficult. Some of the

low-carbon steels will sound dead under the hammer, but they can usually be separated from a lot of wrought-iron bars, as the surface of the latter is generally very much rougher than that of steel bars. Then, too, breaking a small piece from the end of a bar will show the difference between steel and iron, steel having a crystalline appearance, while the fracture of the iron presents a fibrous appearance. The emery-wheel test, however, is said to be the best for distinguishing different grades of steel. Hardened carbon steels give off bright dazzling sparks when ground on an emery wheel; the harder the steel, the brighter the sparks. Alloy steels and wrought iron give off dull red sparks.

9. Breaking Off Carbon Steel.—Carbon steel is generally broken by nicking it, placing the nicked edge over the edge of the anvil and striking the projecting end. Sometimes the end of a light bar is passed through the hardie hole or the pritchel hole until the nick is in line with the top of the anvil; the bar is then broken by jerking it quickly to one side. Another method for breaking off pieces of tool steel, such as those used for cold chisels, lathe tools, etc., is to nick the bar cold at the required distance from the end and pass the bar through a hole in a swage block until the nick comes opposite the edge of the block; the projecting end should then be struck a sharp blow with the hammer. This will break off the piece without stinging the hand supporting the end of the bar, and prevent the piece from flying across the shop. Carbon steel may also be severed from the bar by cutting it while hot or by sawing.

10. Cutting Off High-Speed Steel.—When high-speed steel is nicked and broken from the bar, the structure is usually injured. For this reason, high-speed steel should never be broken from the bar but should be severed from it by cutting. The circular cold saw and power hack saw are most commonly used for this purpose. The saws used to cut high-speed steel should themselves be made of high-speed steel. When a large amount of small stock is to be cut from the bar, the stock may be formed into bundles, and, by holding the bundles very rigidly, no difficulty will be experienced in cutting them.

11. Heat-Treating Operations.—The properties of steel, such as hardness, toughness, etc., may be modified by heat treatment, which consists of heating the steel to certain temperatures and then cooling it in various ways. The usual heat treatments are *annealing*, *hardening*, and *tempering*.

Annealing is a term applied to the operation of heating steel to about a cherry red and then permitting it to cool slowly, thereby causing it to become soft and of uniform structure throughout.

Hardening is a term applied to the operation of heating steel to about a cherry red and then cooling it suddenly. The steel is usually cooled by plunging it in water. The degree

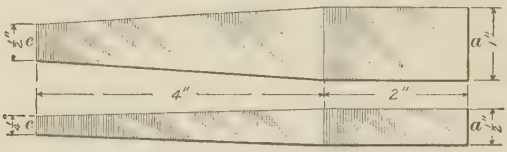


FIG. 1

of hardness depends on the amount of carbon in the steel, the temperature to which it is heated, and the suddenness with which it is chilled.

For hardening, high-carbon tool steel should be heated to from 1,400° F. to 1,475° F., and never above 1,500° F. If high-speed steel is heated to 1,800° or 2,200° F. and cooled in a blast of air, or in warm oil, the steel will be hardened.

Tempering is a term applied to the operation of reducing the hardness of steel to any desired degree. If a hardened piece of steel is slowly heated, it will gradually become softer as the temperature rises; when the desired reduction in hardness is obtained, any further softening of the steel can be prevented by dipping it into some cold liquid. The hardness of the steel after the tempering process is also known as its *temper*.

12. Temper Colors.—The temper of hardened steel may be drawn by the aid of what are known as temper colors. Suppose the end *a*, Fig. 1, of the hardened wedge is laid on a piece of hot iron while the end *c* of the wedge is laid on a piece

of cold iron. The large end *a* will rapidly become hot from its contact with the heated bar of iron, while the other end *c* will warm up very slowly. Soon it will be noticed that colors have begun to appear on the surface of the steel. A very pale yellow starts at the hot stock and creeps toward the small end, being followed by a darker yellow, then by a brown, and so on, until by the time the yellow is close to the small end, the large end is of a deep slate color.

The colors produced in tempering steel tools are caused by the oxidation of the surface of the steel. The color varies with the temperature, and indicates the temperature to which the part has been heated.

The colors in their regular order, beginning with that indicating the greatest hardness of the steel, are generally known by the following names: very pale yellow, pale yellow, light straw, full yellow or straw, dark straw, brown, brown with purple spots, purple, dark blue, full blue, light blue, and gray.

13. Table I shows what colors are produced at various temperatures, and it also gives the names of a few tools or instruments usually tempered to the various degrees of hardness obtained at these temperatures. The temper should be drawn slowly, as it is then easier to watch changes of color and the danger of drawing it too far is reduced. Furthermore, when the temper is drawn slowly, the length of the part drawn to the desired color will be greater, which will permit the tool to be reground oftener before rehardening is necessary. Different makes of steel vary somewhat as to the degree of hardness corresponding to a given color, but the table may be taken as representing a fair average.

By examining the gradations of color on the accompanying chart of Temper Colors and Approximate Temperatures through a narrow slot, say $\frac{1}{8}$ inch by $1\frac{1}{2}$ inches, in a piece of white paper or cardboard, an approximately correct idea of the various temper colors given in Table I may be obtained. The opening in the cardboard should be placed opposite the name of the color to which the temper of the steel is to be drawn. It should be borne in mind, however, that the color

TABLE I

TEMPER COLORS AND CORRESPONDING TEMPERATURES OF STEEL

Color	Temperature, in Degrees Fahrenheit	Kind of Tool
Very pale yellow	430	Scrapers, light-turning tools, lancets
Pale yellow	450	Razors, surgical instruments
	460	Lathe tools, milling cutters
Full yellow, or straw	470	Penknives, drills for iron
Brown	490	Taps, reamers, dies for screw cutting, small cutlery, shears, flat drills
Brown with purple spots	510	Axes, planes, pocket knives, wood chisels
Purple	530	Twist drills, cold chisels for very light work, table knives, large shears
Dark blue	550	Wood saws
Full blue	560	Stone-cutting chisels, fine saws, daggers
	580	Carving knives, springs
Light blue	600	Drills for wood, cold chisels, swords
Gray	700 to 750	

TEMPER COLORS AND APPROXIMATE TEMPERATURES

Approx. Degrees F.	*Colors*
725.	Gray
600.	Light blue
560.	Full blue
550.	Dark blue
530.	Purple
510.	Brown with purple spots
490.	Brown
	Dark straw color
470.	Full yellow, or straw color
	Light straw color
450.	Pale yellow
430.	Very pale yellow

values of the chart are not in any sense fixed or absolute for different grades of tool steel exhibit different gradations of color when tempered. Practice in tempering any given grade of steel is therefore necessary in order to determine whether the degree of hardness corresponding to a given color on the chart is such as to enable different tools to meet the requirements of the work for which they are intended. The chart will, however, serve as a guide in determining the characteristic qualities of various grades of steel.

14. Working Tool Steel.—Tool steel must be carefully heated for working. The heating must be uniform, for, unless the metal is uniformly heated, violent stresses are liable to be set up in it which will cause cracking in hardening. If the steel is heated so that the outer parts are hotter than the center, the outer portion will be forged by the hammer blows while the inner portion will remain nearly in its original form. Forging at too low a heat will injure the steel in the same manner as uneven heating.

The steel should be heated thoroughly to make it plastic before working. The heat required varies, with the steel, from a cherry red to a bright yellow heat, or from about 1,400° to 1,600° F. The heat required for working any particular steel is usually specified by the steel maker or it may be determined by trial. To avoid oxidizing the steel, when the heating is done with a solid fuel, the steel should be surrounded by plenty of fuel so that the air blast will not come in direct contact with it.

A fire made of clean soft coal that has been well charred or coked is well suited to heating for working, but as steel absorbs sulphur readily and as sulphur is very injurious to steel, care must be taken either to use a fuel low in sulphur or to remove as much sulphur as possible by heating a heavy bar of iron in the fire for about 10 minutes. The iron will absorb most of the sulphur and the fire is then ready to heat the steel. Care should be taken not to let the steel lie in the fire and soak up heat after it has become hot enough to work, as *soaking* is injurious. **Soaking** consists in heating the steel so slowly that

there is a loss of carbon from the surface of the steel, and as a result the surface becomes too soft. On the other hand, too rapid heating to too high a temperature results in overheating, or burning, the steel, and in unequal expansion in the piece, which may cause it to crack when being hardened.

15. After the steel has been properly heated it should be worked fast, using rapid hard blows and reducing it with one heat to as nearly as possible the size and shape wanted. If cracks or flaws appear, the steel has been overheated and should be discarded; if none appear, it has not been injured by the heating. If the piece has been formed to nearly the desired size by the first working, it need not be heated so hot for the second working. The finishing off of the corners, edges, and flat surfaces, and the bending and straightening may be done at a lower heat than that required for the first working. Generally, a steel containing not more than 1.20 per cent. of carbon will stand a bright yellow heat for forging, and if it is desired to reduce it as much as one-half in size it should be brought to this heat. If it is then hammered promptly and thoroughly on first one side and then the other until it becomes dull red, the steel will be as tough and strong as it can be made by forging. If it is not well hammered it will be weak and coarse-grained.

16. Welding Tool Steel.—Welding tool steel is a difficult operation and should be avoided where possible, especially if the steel is to be hardened subsequently. When two pieces of steel are heated for welding and are exposed to the air, they become covered with a scale of oxide of iron. To secure a perfect contact of the parts, this oxide must be made so fluid that it will readily squeeze out from between the surfaces to be welded. To do this, either the steel must be heated to the temperature at which the scale will melt, which will be a very high temperature, or some means must be used to fuse the scale at a temperature below that at which the steel would be injured. This is done by applying to the heated parts a flux that melts and adheres to the heated surfaces, preventing excessive oxidation and, at the same time, uniting with the

scale to form a mixture that is fusible at a much lower temperature than would be necessary to melt the scale alone. Borax is commonly used for this purpose.

Before attempting to weld any grade of steel, the smith should know its quality and how its structure and welding properties will probably be affected, if they are affected at all, by varying both the temperature to which it is heated and the method by which it is worked. This information is furnished by the steel maker or it may be obtained by tests made on specimen pieces.

17. The structure of the steel, which means the size of the crystalline grains of which the steel is composed, is affected by the temperature to which it is heated, the amount and character of the subsequent working of the metal in making the weld, the heat of the metal when the forging work on it is discontinued, and the rapidity of the final cooling. Some steels will withstand a greater heat than others without injury, but, in general, the most important points to be observed are the methods of working and cooling the steel. It seems to be established that the greater the amount of carbon that a steel contains, the lower is the temperature to which it may safely be heated. If the steel is heated to a full red, or above, for welding, and the work of making the weld is done quickly, leaving the metal still at a high temperature, the metal, if allowed to cool slowly, will be coarser grained and more brittle than when the forging is continued until the temperature of the steel falls below that of a low red and the metal is allowed to cool slowly from that point. On the other hand, if, after having finished working, the steel is cooled suddenly to a low red heat by being plunged into water, and then allowed to cool slowly in a dry place, the quality of the grain and the strength of the piece will be superior to that which would result from allowing it to cool slowly from the higher temperature.

18. If the piece is cooled suddenly from the temperature at which the work was finished to the temperature of the air, by quenching in water, the size of the grain and the strength of the steel will in all probability be superior to that obtained

by allowing the steel to cool slowly in the air. Cooling rapidly from a too high heat is, however, likely to crack or break the steel.

With carbon steels, the tempering heat is lower than the annealing heat; the annealing heat is the same as the hardening heat; and the hardening heat is lower than the forging heat. The only exception is in the case of the high-speed alloy steel.

In making a number of articles of steel, should a defect appear always in the same place, it is likely that something is wrong with the method rather than with the steel.

EXAMPLES OF TOOL DRESSING

CARBON-STEEL TOOLS

CHISELS AND HAMMERS

19. Making a Flat Chisel.—If it is required to make a flat chisel of the form and dimensions illustrated in Fig. 2, a piece about 6 inches long is first cut from a bar of $\frac{3}{4}$-inch octagon steel. The piece is then put into the fire so as to heat the end, for a distance of about 2 inches, to a cherry-red color. The

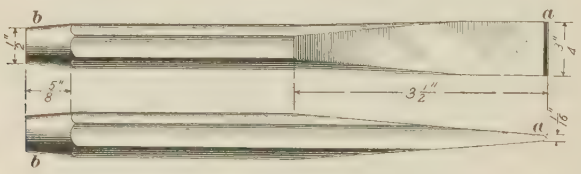


FIG. 2

fire must be clean and the heat must be raised with sufficient rapidity to prevent soaking the steel, and yet heat the piece thoroughly without burning the corners.

When a cherry-red heat is reached, the end of the piece is drawn to a wedge shape by rapid blows on a set hammer. If the end of the chisel is spread sidewise during the working, it is now brought back into shape by a few hammer blows on the

edges; all the edgewise hammering should, however, be done early, and not when the heat is low. The end is then drawn to an edge *a* by light hammer blows, taking care not to work it below a black heat, as this would tend to crack it. When the edge has been drawn out, the rough or ragged part is cut off with the hot cutter, laying a piece of soft iron between it and the anvil so as to avoid cutting against the hardened face of the anvil and spoiling the hot cutter. The head of the chisel is then rounded, as shown at *b*.

20. In most cases the piece should be annealed in order to make it homogeneous; although the annealing is often neglected, better results are obtained when it is done. When steel is worked, its structure changes, and in the case of the chisel, the thinner part—having been worked more than the thick part, and having been heated more rapidly to a higher temperature, and also having been cooled more quickly by the cold anvil and hammer—is more likely to be brittle and no longer uniform in structure. Its structure should be made uniform, however, before hardening; otherwise, the various parts are likely to be hardened and tempered unevenly. The process of heating for hardening the tool does much to restore the uniformity of steel, but often this is not sufficient, and for this reason it is preferable to anneal every tool before it is hardened. To anneal the steel, it is put into the fire and heated to a red heat, care being taken not to overheat the thin edges. When uniformly heated, it is taken from the fire and placed in the warm ashes on the side of the forge, and allowed to cool until the heat produces no visible color when the piece of steel is held in a dark place, as under the forge; and then it may be cooled by being plunged into water. This makes its structure uniform once more, and it is ready to be hardened.

21. In order to harden the chisel, it is heated to an even red color, a little below the forging heat, allowing the point to extend a little beyond the hottest part of the fire. It is then plunged endwise into cold water, care being taken to plunge it in straight, letting the sharp end strike the water first. It should be thrust down vertically, then moved up and

down and turned around, in order to bring its surface in contact with as much cold water as possible, thereby cooling it rapidly. If plunged sidewise, one side will cool sooner than the other, and the piece will warp or crack. The warping would not be a very serious defect in a cold chisel, but it would be in finer tools, and carelessness in making rough tools might lead to carelessness in making finer ones. When plunged, the work should not be held quietly, because the hot tool transforms the water with which it comes in contact into steam, which envelops the steel and keeps off the cold water; by moving the piece continually it is chilled more effectively. Moving the steel from side to side, however, has the same effect as that of plunging it sidewise. The bath should be kept at a temperature of about 60° F. The water should be free from acid, soap, or grease, and, when possible, should be soft.

22. When properly hardened, the faces of the chisel are rubbed bright with emery cloth or sandpaper, or a piece of grindstone, so that the colors can be watched while drawing the temper. If the body of the chisel is now heated slowly by holding it across a bar of hot iron, the temper will be drawn gradually, and when the brown color reaches the cutting edge, the chisel is dipped into water to hold the temper where it is. The chisel can then be ground on a grindstone and tried on a piece of iron. The point should be the hardest part of the chisel.

23. In practice, a cold chisel is generally hardened and tempered in one heat. The cutting end is heated to a red color, letting the heat extend pretty far back, say about 3 inches. It is then taken from the fire and the point plunged into cold water about 2 inches. In plunging a piece of steel in this way, it must be moved up and down a little, so as to avoid starting a water crack between the hardened part and the soft stock. As soon as the point has been sufficiently chilled, it is polished quickly. The heat still retained in the stock will gradually run to the point and draw the temper, and the colors can be watched on the bright part. When the desired color is reached at the point, the chisel is dipped into cold water to hold the

temper where it is. Should the colors come too fast, after dipping, the chisel may be dipped a second time and the drawing

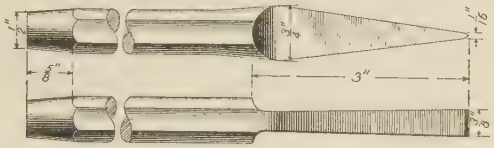


Fig. 3

operation repeated; while if they come too slow, their coming may be hastened by moving the point over the fire, taking care not to heat it too much.

In dipping tools for hardening or tempering, great care must be taken to keep them in the water long enough to chill the steel throughout. When the tool is dipped, the outside becomes chilled and contracts, forming a hard, brittle shell for the heated interior mass of metal. As the latter cools it also contracts, but being held to the already hardened external shell it cannot contract to its original size, and hence there is produced an internal stress on the steel that may cause it to crack. To prevent cracking, the steel should not be plunged when heated beyond a red heat.

24. Making a Cape Chisel.—Suppose a cape chisel of the form and dimensions shown in Fig. 3 is to be made. The heated end of the bar of steel is first laid across the rounding edge of the anvil, the end of the bar toward the hand being below the face of the anvil, as shown in Fig. 4. The first forming, which is begun at a distance from the end of the bar that will give sufficient metal for the chisel, is for the shoulders of the sides where they widen into the handle of the chisel. To form these shoulders, the fuller is used over the rounding edge of the anvil, care being taken to have the shoulders equal and opposite each other. The piece is turned frequently, so that the effect of the work may be seen

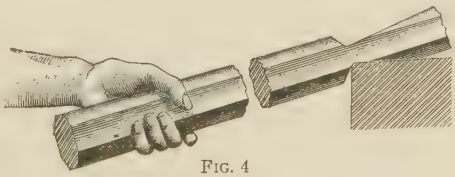


Fig. 4

and the sides kept alike. After the shoulders have been formed, the stock on the sides may be drawn down slightly with the fuller and the sledge and hammer are used to bring the chisel, roughly, to the form shown in Fig. 3. The finishing is done with the use of a hand hammer or a flatter. When properly formed, the chisel is cut from the bar to the required length, which ranges between 6 and 8 inches, and the head is formed, after which the chisel is annealed. The point is then generally hardened and the temper drawn in a single heat, in the same manner as described in connection with the flat chisel.

25. Making a Hammer.—For practice in working tool steel, the making of a cross-peen hammer, like that shown in Fig. 5, is useful. Two hammer heads may be made at one

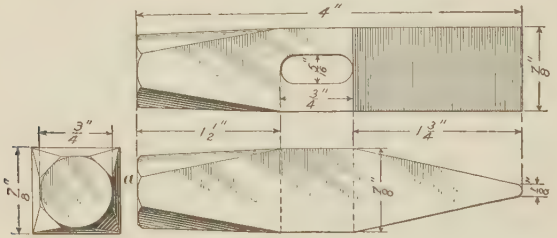


FIG. 5

operation, by using a piece of tool steel $\frac{7}{8}$ inch square and $5\frac{3}{4}$ inches long. When the face end *a* of the hammer is drawn out to the form shown, the change in section from the square to the octagonal, and the slight taper from the eye to the face, will increase the length by $\frac{1}{4}$ inch, or more. As it is advisable to form the eyes before drawing out the ends of the hammers, the centers of the eyes are prick punched on each end of the stock. The distance of these centers from the ends of the stock is equal to $1\frac{1}{2}$ inches plus $\frac{3}{8}$ inch (one-half the length of the eye), less $\frac{1}{4}$ inch (the amount the face end will be drawn out), or $1\frac{5}{8}$ inches. Having marked the centers $1\frac{5}{8}$ inches from each end, the holes for the handles are next punched with an eye punch that is considerably smaller than the required hole. The punch is first driven half way through from one side and then half way through from the other side. The holes are

finished by driving into them, from first one side and then the other, what is known as a **drift pin,** that is, a pin of the required size and shape. To make the opening the proper shape, it is necessary to work the pin, or drift, into the hole made by the punch, very carefully, keeping the steel closed around the drift during the operation of shaping the hole so that the hammer handle may be wedged in it. The stock must be hot enough to work freely.

26. One of the face ends *a*, Fig. 5, is now drawn out to the required form. This end is then held in the tongs while the other end is treated in the same manner. The stock is next cut apart at *c*, Fig. 6, and the peen ends are drawn to the form and dimensions shown in Fig. 5. Ball-peen hammers and

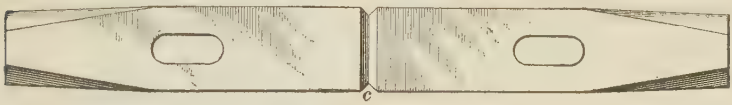


FIG. 6

those having other shapes may be made in nearly the same manner. The drawing may be done with a hand hammer, or with the fuller and flatter.

27. A machinist's or blacksmith's hammer is usually hardened by grasping the peen end in a pair of tongs and heating the face end by thrusting it only a little way into the fire, turning it frequently. There is danger that the outside corners will be overheated before the center of the hammer face is hot enough to harden properly. The easiest way to avoid this is to heat slowly, though care must be taken not to let the heat run too far back toward the eye. Some smiths cool the corners of the hammer slightly by dipping them into water, holding the hammer nearly flat and revolving the corners in the water. The hammer is then replaced in the fire until it is brought to the hardening temperature, usually a dull red, when it is hardened by dipping the face about $\frac{1}{2}$ inch into the water, and moving it about quickly with a circular motion. The hardness should be tested with a file, both in the center and at the corners, and if sufficiently hard the face may be

brightened with emery paper or a piece of grindstone, and the temper drawn to a purple or blue by the heat remaining in the body of the hammer. The hammer may then be cooled in water sufficiently to arrest the temper-drawing process. The same operation is repeated in hardening and tempering the peen end of the hammer, care being taken to keep the face end cool by sprinkling with water if necessary. The eye of the hammer is not hardened.

LATHE, PLANER, AND SLOTTER TOOLS

28. Models.—If the best results are to be obtained from the tools used in the machine shop, only the best forms should be employed for each particular operation; hence, the shop superintendent should determine the best forms for the work to be done, adopt a set of standards, and three sets of iron models of these tools should be forged. One of these sets should be ground to the proper form, mounted on a board, and retained in the tool room for reference; the other two sets of forgings should be mounted on boards, one board being kept in the tool room and the other mounted near the tool-dresser's fire. No tool that varies from these forms should be made or used except on special written order from the superintendent or foreman.

29. A few typical lathe tools are shown in Fig. 7, a few typical planer tools in Fig. 8, and in Fig. 9 some slotting and other special tools. Figs. 10 and 11 illustrate charts that are furnished with the Sellers' grinding machine that give the clearance angles for grinding the different tools. The angles to which the various sides of the tools would be forged are somewhat larger than those given in order to reduce the amount of grinding required to sharpen the tools. The numbers placed opposite the tools in Figs. 7, 8, and 9 correspond to similar numbers on the shanks of the tools in Figs. 10 and 11. In the case of the side-finishing planer tools illustrated in Fig. 11, it will be noticed that two angles are given for *d*. The upper angle is the top side rake, at right angles to the cutting face, and the lower angle is the top rake in the direction of the cutting face. These

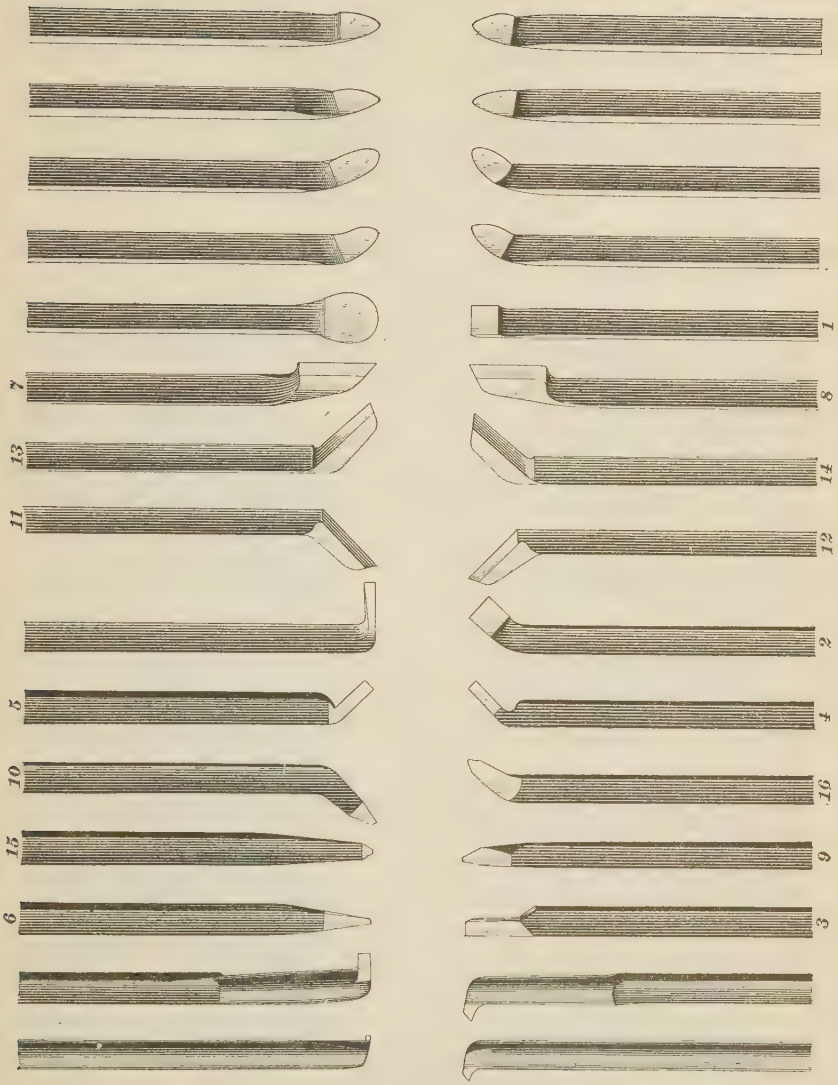


Fig. 7

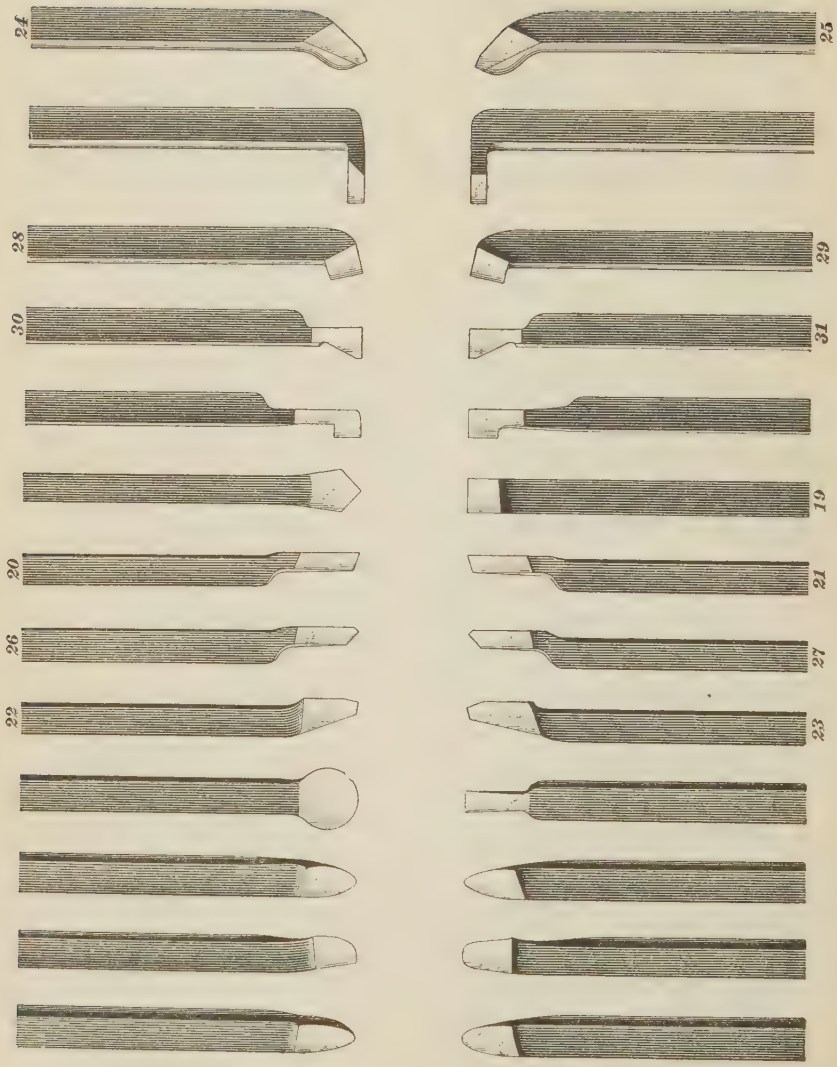


Fig. 8

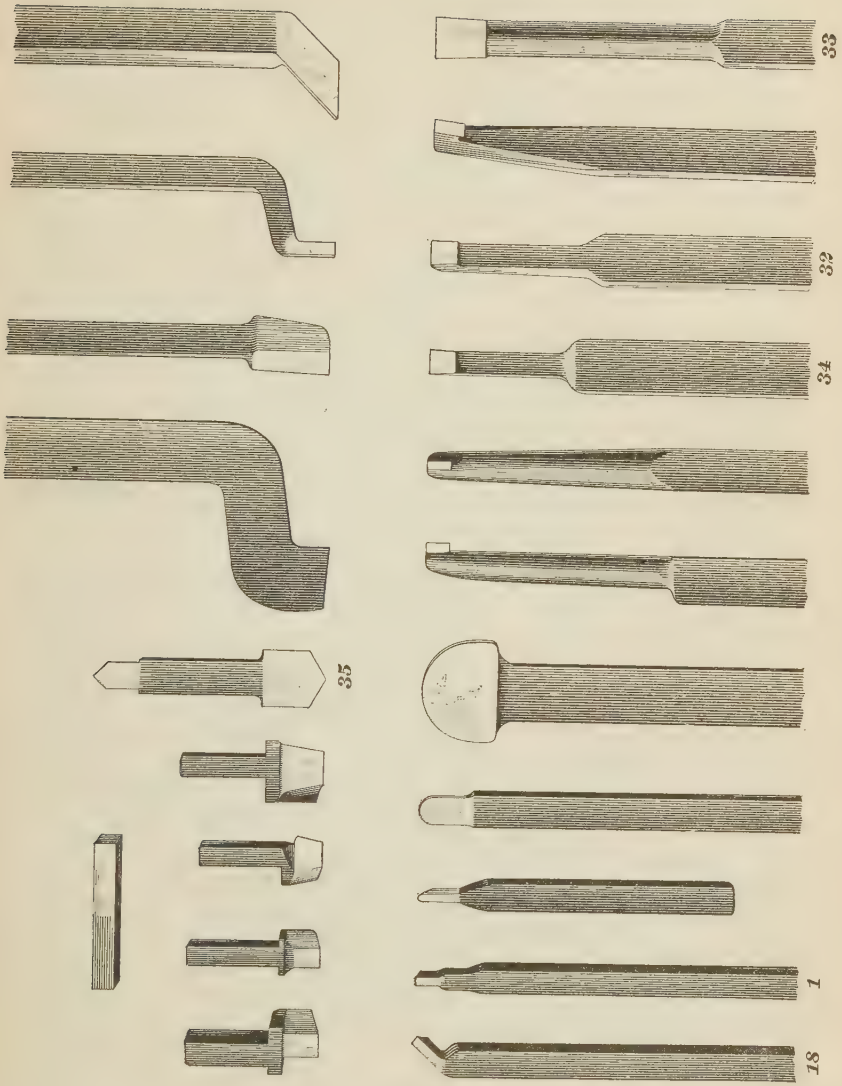


FIG. 9

charts and figures are given simply to show what is considered good practice in regard to the shape of the tools.

30. Diamond-Point Lathe Tool.—Suppose the right-hand, diamond-point lathe tool shown in Fig. 12 is to be made.

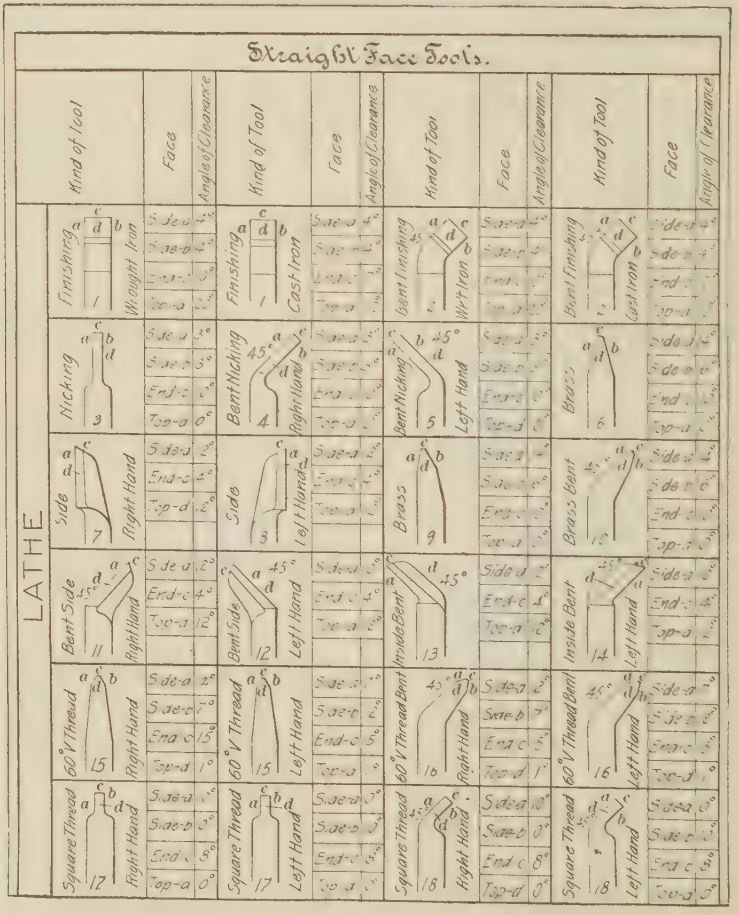


Fig. 10

For a small tool, stock $\frac{1}{2}$ inch by 1 inch in section may be selected; the length of the stock required would be about $\frac{1}{2}$ inch less than the desired length of the tool. To make the

tool, one end of the stock is squared and a $\frac{1}{16}$-inch bevel e is formed on the edges, after which the other end of the stock is drawn to the form shown in Fig. 13 (a). This end is next drawn to the form shown in (b), after which the edge b is placed

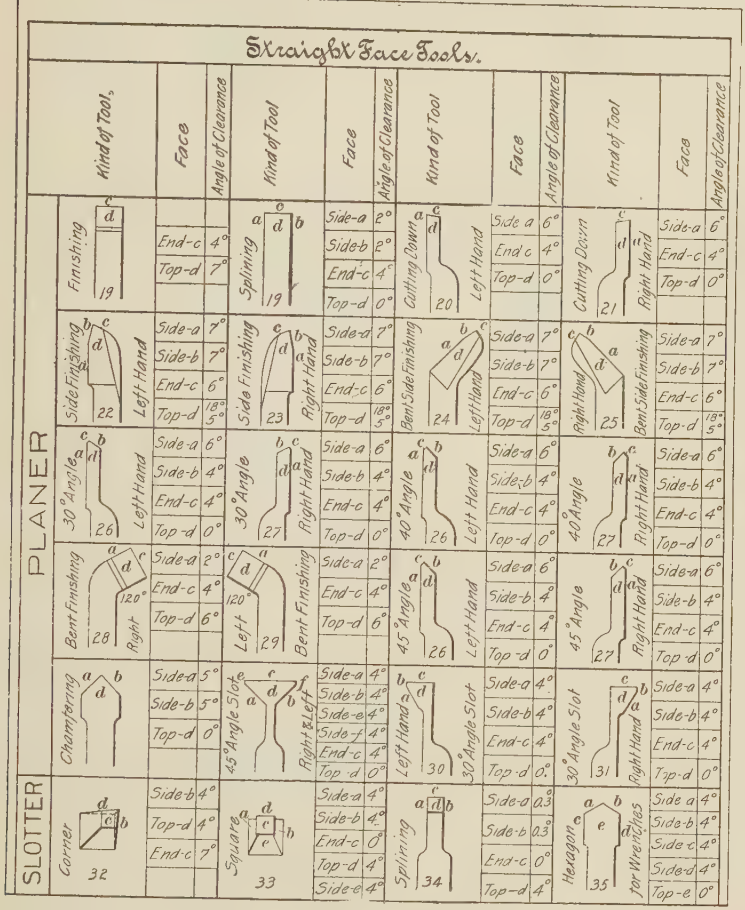


Fig. 11

in contact with the face of the anvil, the body of the tool being held obliquely across the side, as shown in Fig. 14 (a). A few blows are then struck on the uppermost corner of the work. The position of the tool is now shifted until the tool is in the

position shown in (*b*), and a few blows are struck on the corner now uppermost. The tool is now returned to the first position and a few blows struck, after which it is changed again. This

FIG. 12

operation is continued until the end is square in section and of the form shown in Fig. 12. The point *f*, Fig. 13 (*b*), is next cut off at an angle, as shown in Fig. 12, with a sharp cutter, the direction of the cut being from *d* to the opposite corner. The point is then bent to one side, as shown. Care must be taken not to work the steel at too low a temperature to prevent a crack forming at *a*, Fig. 12.

The tool is next hardened and the temper is drawn to a light straw color for about $\frac{1}{4}$ inch back from the cutting edge. The hardening and tempering are done in the same manner as described for the cold chisel.

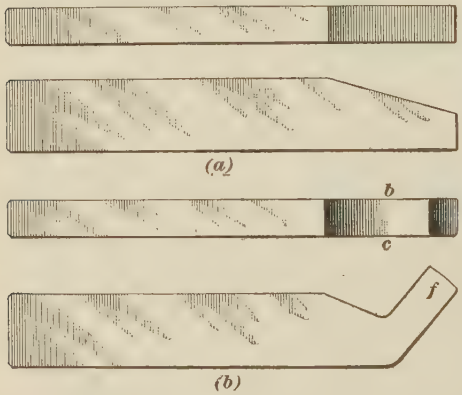


FIG. 13

31. Right-Hand Side Tool.—If a small right-hand side tool, Fig. 15, is to be made, a piece of stock $\frac{1}{2}$ inch by 1 inch in section may be selected. One end of it is then beveled as shown at *a c*, Fig. 16 (*a*), the distance from *a* to the end of the bar being about $1\frac{3}{4}$ inches. The stock is next placed on the anvil so that the corner *a* is over the rounded edge, the piece being held as shown in (*b*). It is then driven down with blows delivered in the direction of the arrows in (*c*). This will bring

it to the shape shown in (*d*), the edge *c d* being made thinner than the bottom *e f*. When it is forged to the right thickness, the edge and point are cut off with a hot cutter to the shape indicated by the dotted lines. The edge *c d* must be straight when finished, and it must be above the top of the bar so that a number of grindings may be made before redressing is necessary. After the parts are made of the required thickness and dimensions, the edge is set over to one side in the manner shown in (*e*), the piece being placed over the rounded edge of the anvil and the set hammer used as indicated.

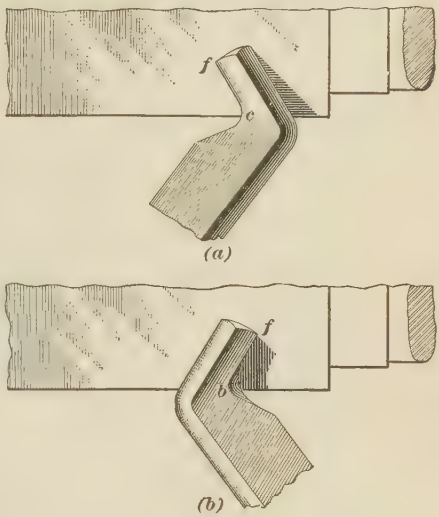


FIG. 14

The temper should be drawn to a dark straw color. Care must be taken not to overheat the thin edge, and it is well to dip this tool as shown in (*f*); this leaves the heel *a* red hot, and provides a source of heat for drawing the temper.

32. When a large number of side tools are to be dressed, it is advisable to use special swages, one form of which is shown in Fig. 17. This one is used for either right- or left-hand side tools. When the swage is to be used, the stock is first beveled as shown in Fig. 16 (*a*), after which the swage is put in the hardie hole, and the tools are formed in the swage by the use of a flatter.

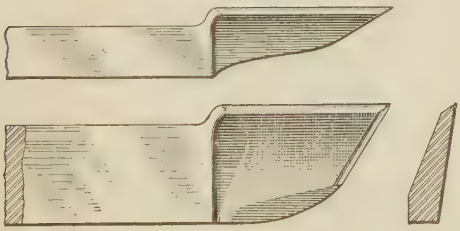


FIG. 15

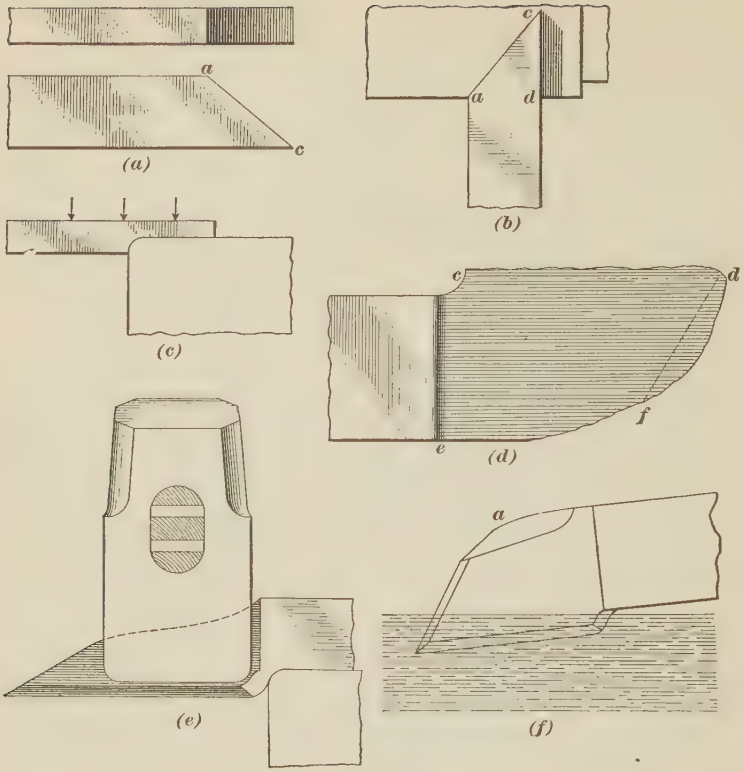


FIG. 16

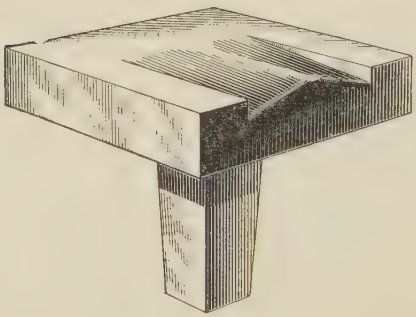


FIG. 17

33. Boring Tool.—To make the boring tool shown in Fig. 18 (*a*), the proper amount of the end is first drawn down with the sledge and hammer to the form shown in (*b*). Then $\frac{1}{4}$ inch of the end is placed on the anvil, the shoulder shown at *a* in (*c*) is formed, and the end is bent to the shape shown

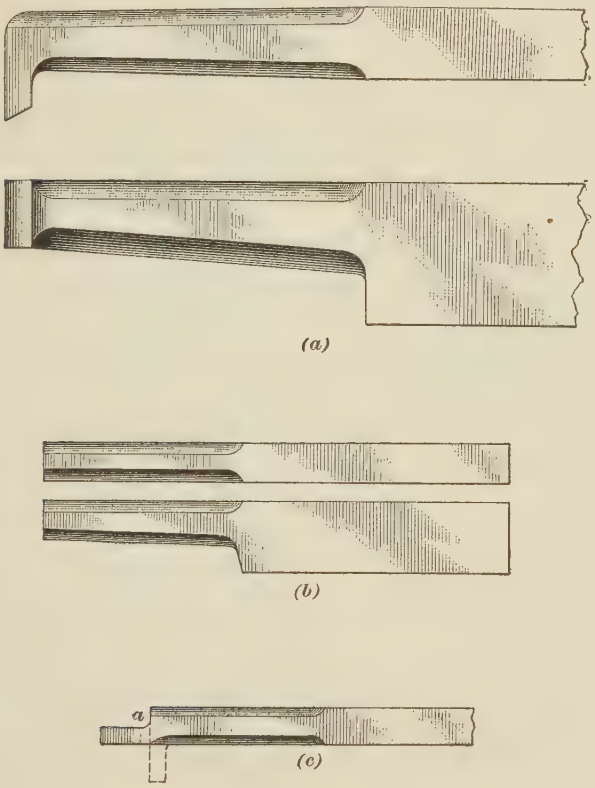


FIG. 18

by the dotted lines. The point is next cut to the required shape with a sharp hot cutter.

The tool is tempered to a dark straw color, as was the side tool. In most cases, only the cutting edge is left hard, the temper being drawn by allowing heat from the body of the tool to run to the point. In the case of very long slender tools, the

entire length of the drawn-out portion of the tool is sometimes hardened to give stiffness to the tool. The neck is then drawn to a spring temper by heating over a bar of hot iron.

FLAT DRILLS

34. The point of a long-shank flat drill, such as is shown in Fig. 19, is made of steel, but the shank is usually iron. To weld both parts together, the steel is formed as shown at *a*, Fig. 20, and the iron as shown at *b*. The iron is then heated to a red heat, the cold steel is driven into the cleft, borax is put on the joint, and the iron is closed about the steel, after which the work is heated to a welding temperature. As the iron forms the outside of the joint, the steel is protected from overheating. When heated to a welding heat, the pieces are taken from the fire and welded together. The shank is then cut to the proper length, the end forged square to fit into the brace or ratchet, and the point forged to the proper form.

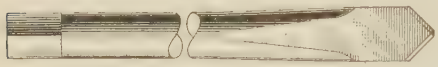


FIG. 19

When forged, the drill is first annealed, next hardened, and its temper is then drawn to a full yellow color. The temper of the drill may be drawn by the heat in the shank. If the shank is not hot enough, a large nut or heavy piece of iron having a hole through it may be heated and slipped over the shank close to the point, the drill being held so that it does not

FIG. 20

touch the hot iron. The heat that radiates from the iron will soon draw the temper. A pair of hot tongs is often used for drawing the temper, the work being held by the tongs near the point of the drill. The heat from the tongs will draw the temper of the drill point. When the desired color appears on the point, the tool is quenched to prevent further drawing.

SPRINGS

35. Making of Spring.—To make a flat spring, like the one shown in Fig. 21, a piece of steel is drawn out flat and

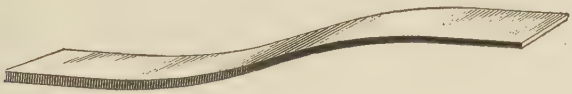


FIG. 21

slightly tapered, care being taken to make the taper very regular. The flat surfaces are finished with a flatter. The steel is then annealed and filed or ground on a stone to remove all irregularities and uneven spots. It may then be bent cold in the hand, or over the horn of the anvil without hammering; or it may be heated and then bent into the shape shown. When evenly bent it is ready for hardening.

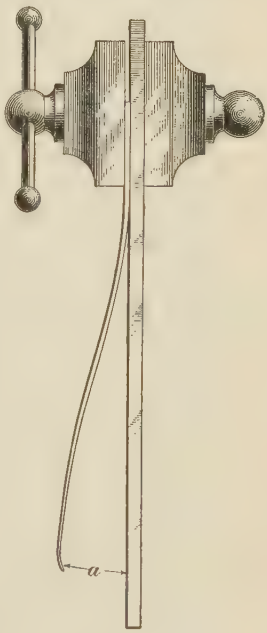


FIG. 22

36. To harden it, the entire spring may be slowly and evenly heated in an open fire or in a pan of sand. After the piece has been raised to a cherry-red heat it is cooled in oil or water. When cooling the spring, it may be held in the tongs and dipped vertically. After being cooled, the surface may be tested with a file to determine if it is hard enough; if not hard enough, the hardening process should be repeated.

37. When hardened, the steel is rubbed bright with emery cloth and then tempered to a dark blue color. The tempering can be done over the open fire, or in a sand bath previously heated to the proper temperature, or over a piece of hot iron. When drawn to a dark blue color, the spring is plunged into cold water.

The temper may be drawn by holding the spring over the fire and heating it slowly and evenly by moving it back and forth, a light draft being used. To know when the spring has reached the right temperature, a pine stick, sharpened to a point, is rubbed over the surface; when sparks follow the stick the right temperature has been reached and the spring is then plunged into oil or water. Care should be taken to heat and cool the spring evenly and to keep it out of drafts when heated in order to prevent it from warping and cracking.

The temper of springs may also be drawn by a process variously known as *burning off*, *flashing off*, and *blazing off*, that is described in *Hardening and Tempering*.

38. Testing of Spring.—The spring may be tested as follows: Its shape is first marked off on the bench or on a sheet of paper, then it is clamped in the vise at the thicker end and the projecting thin end bent forwards and allowed to spring back several times. The spring is then compared with the drawing to see whether it has changed its form. If so, it is too soft; if it breaks, it is too hard. Or it may be clamped in a vise with a piece of iron, as shown in Fig. 22, and the distance *a* measured; it is then forced down until the point touches the iron. After it is released, if the distance *a* measures the same as at first, it is properly tempered. The spring must not be struck or dropped after it is tempered, as it might thereby be broken.

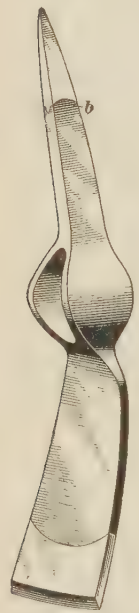


FIG. 23

STEELING

39. Steeling a Pick Point.—The operation of welding a steel edge or point on a tool having a wrought iron stock is termed *steeling*. Owing to its strength, the cleft weld is generally used for this purpose. If the point *b* of a pick mattock, shown in Fig. 23, is to be steeled, the iron is split open, as shown at *f*, Fig. 24, and prepared for a cleft weld. The bar of

steel *d* is then scarfed on both sides, as shown, both pieces heated, and then welded together. After this the point of the pick is drawn out to the required shape. Picks, axes, adzes, and similar tools, are generally steeled in this way.

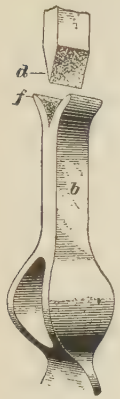


FIG. 24

40. Steel Facing.—When a sheet of steel is welded to an iron back, the operation is called *steel facing*. A thick piece of steel is frequently welded on and the iron and steel are then drawn out thin. Cutters for wood-planing machinery are sometimes made with steel faces and iron backs.

FIG. 25

The iron *i* and steel *s* are first welded together as shown in Fig. 25, and then drawn down to the required thickness.

SPECIAL TOOLS

41. Stone Chisels.—For carving and lettering stone, special chisels are used with wooden mallets. They have a ball-shaped head, as shown in Fig. 26, and the body is swaged down tapering under the head; this lightens the chisel and gives it a better balance in the hand. These chisels are made of $\frac{1}{4}$-, $\frac{1}{2}$-, $\frac{5}{8}$-, and $\frac{3}{4}$-inch octagonal steel. In making these chisels, the pieces of steel are cut off at a proper length for two chisels, and the ends of six or eight pieces are placed different distances into the fire. The one farthest in the fire will arrive at the proper heat first. It is then removed, gripped in a vise, and quickly upset by a few blows of a light sledge and the blacksmith's hammer. The hot steel is then removed to a hardened-steel die, or swage, *d* on the anvil shown in Fig. 27. This die rests loosely on the face of the anvil, and is held in place by the saddle *e* placed across the anvil. The clamp *f*, fastened with two setscrews, helps to retain the die on the

anvil. A top swage *g*, with a handle about 1 foot long, is also used. The ball head of the chisel is formed between the top and bottom swages, which also form the taper neck under the head, the steel being rotated during the operation. Sometimes there will form at the center of the head a small teat, which can be knocked off with a hot cutter by a single blow of a light sledge. By the aid of these tools, only a few seconds are required to form each head, a new piece of steel being put into the fire at the same time the hot one is removed. After the head is finished on one end of the steel, the other end of it is placed in the fire. When nicely polished swages are used, the chisel heads formed have a smooth finish. This is desirable in order that the wooden mallet used on them may last a long time. The center of the head is usually touched on an emery wheel to smooth it.

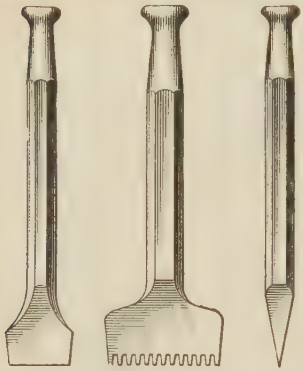
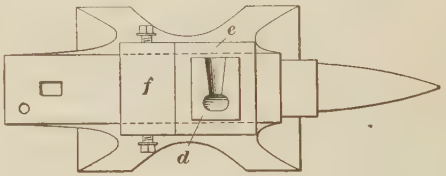


FIG. 26



42. After both ends are headed, the pieces of steel are cut in the middle and drawn out into long, slender wedge-shaped chisels. The teeth are then marked off with a three-cornered file, after which they are cut while hot with a chisel shaped like the teeth. Or, a cutter of the desired form may be placed on a grinding-wheel arbor and used to saw the teeth of the chisel.

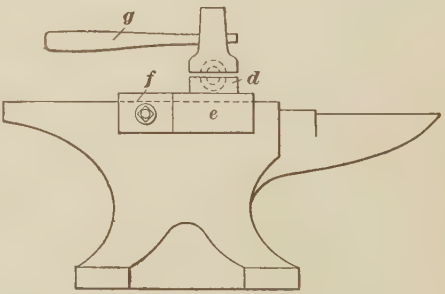


FIG. 27

The cutter is made of tool steel. Its diameter may be about 8 inches and its thickness at the hub about $\frac{3}{4}$ inch. It is made without teeth and is run at a speed of about 2,000 revolutions per minute. When the saw is used to cut the teeth, they are marked off on the chisel and sawed, the chisel being cold. The shape of the teeth depends on the material to be cut. For cutting sandstone, the teeth should be heavy but not sharp, as shown in Fig. 26. For cutting granite, they should be heavy and sharp. For cutting soft marble, they should be light and sharp.

FIG. 28

43. Rock Drills.—A rock drill, known as the *plug and feather drill*, is shown in Fig. 28. As it is used with the hammer, the ball, or mallet head, is not required, and the cutting end of the drill has a blunt taper. A special fixture *h*, Fig. 29, is used on the anvil while dressing the drill. This consists of a block of steel, about 3 inches square and $1\frac{1}{2}$ inches thick, that has a shank fitting the hardie hole; this shank is slotted for a key *i* that holds the fixture firmly to the anvil. The top of the block tapers an amount equal to half the taper of the drill, and its high side is chamfered, as, otherwise, the edge would be likely to chip off. By using this fixture and the special hammer shown in Fig. 30, the drill may be held level while being forged. The ends of the hammer have the same taper as the top of the block. The drill should be turned over occasionally while being dressed.

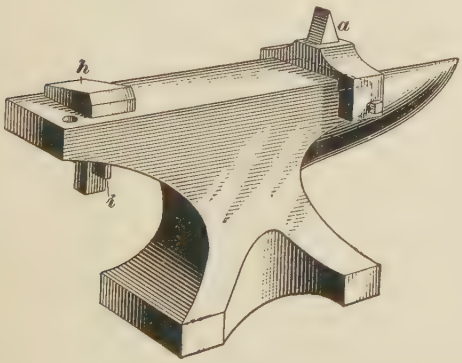


FIG. 29

44. As it is desirable to have a hardie and the special fixture *h*, Fig. 29, on the anvil at the same time when making rock drills, and as the anvil contains but one hardie hole, a special hardie, as that

shown at *a*, may be used. This hardie fits in a square hole in a saddle that is clamped to the anvil by means of setscrews.

Other forms of rock drills are those commonly used by miners to drill through rock. In Fig. 31 (*a*), one form of *hand drill* is illustrated. This drill is made of octagon steel and is forged to the shape shown by drawing out the end of the steel so as to form a cutting edge that is a little wider than the stock. In (*b*), one form of *machine drill* is illustrated. It is forged to the shape shown out of special drill stock that has a cross-section of the form shown in (*c*). The parts *a*, in (*b*), are first tapered by the use of a set hammer, after which the end of the work is heated and then shaped with a steel die of the form shown in (*d*). The part *b* of the die fits in the hardie hole of the anvil. The die

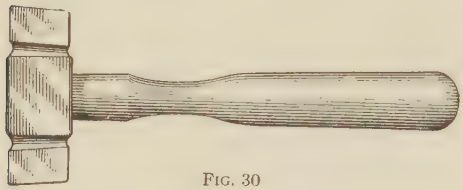


FIG. 30

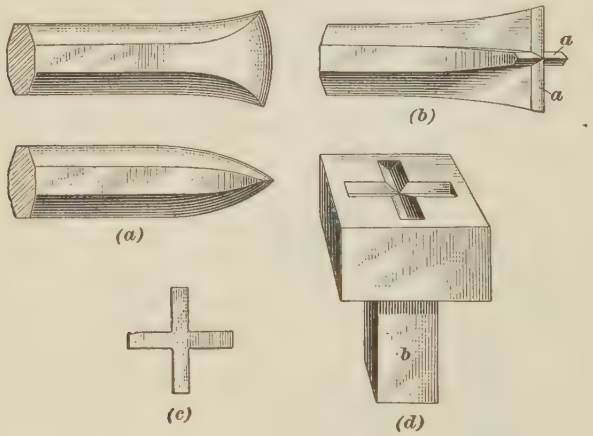


FIG. 31

is also made in the form of a flatter or dolly, provided with a handle, the grooves being cut in the face. The grooves are often made to run clear across the face. In case a die is not available, the cutting edges of the tool may be formed by filing.

After the drills are forged, they are hardened by heating their ends for about $1\frac{1}{2}$ inches to a cherry-red color and then quenching in cold water. If the rock to be drilled is soft, the temper of the drill may be drawn to a light blue color; while if the rock to be drilled is hard, the temper is drawn to a straw color.

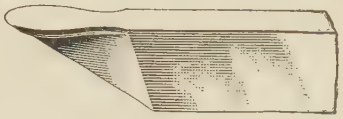


FIG. 32

45. Marble Turning Tools.—For making columns or other round work, marble may be readily and rapidly turned in a lathe. For such work a different form of tool from that used in lathes for turning metals is required, and frequent dressing is necessary. One form of marble turning tool is shown in Fig. 32. This tool has a round cutting edge, although the cutting edge may be oval, square, diamond-shaped, or of any other form. The tool shown may be forged in the steel die shown in Fig. 33, which has a shank that fits the hardie hole of an anvil, the die being used to give the proper shape to the nose of the tool. When the dressing is finished, the tools are hardened, and then their temper is drawn to a straw color.

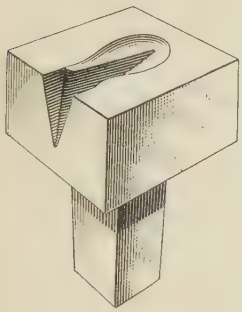


FIG. 33

HIGH-SPEED-STEEL TOOLS

46. Forging.—High-speed steel is largely used for lathe, planer, and similar tools. It is difficult to forge, and forging directions are usually supplied by the steel maker. As a rule, the steel should be heated slowly and thoroughly to a full yellow heat, care being taken not to heat the steel farther back than is necessary to form the tool. The steel should, however, be heated back far enough so that no work will need to be done on the shank while it is below a cherry-red heat. The heating should be uniform and should penetrate to the center of the bar. Frequent reheatings are often necessary to make large

tools. It is essential that the steel is not worked at lower than a bright red heat, to avoid checking and cracking. If heated too rapidly, the steel will not flow freely under the blows of the hammer and cracks are likely to develop, owing to the stresses set up in the steel by the unequal expansion and contraction of the exterior and interior parts.

47. After being properly heated, the steel is forged in the usual manner. If a large tool is being formed, the blows should be heavy enough so that their effect will extend to the interior metal and not be absorbed by the surface alone. If a light tool is being formed, the blows should be relatively lighter. The forging should be done rapidly, being completed in one heat if possible. Tools that require considerable working, however, generally require two or three heats, depending on the tool, the number of helpers, and whether a power hammer is used. It is advantageous to use a power hammer on heavy tools, as better results may then be obtained at a lower cost. To remove the forging stresses, the tools are reheated to a red heat, after the forging is finished, and laid on the floor to cool.

48. Heat Treatment.— High-speed steels may be annealed by packing them in a piece of pipe or an iron box containing powdered charcoal, in which the pieces of steel are embedded. The pipe or boxes are well sealed with fireclay to exclude the air, heated to a bright cherry red for several hours, and then allowed to cool slowly. The steel will machine as easily as carbon tool steel after it is annealed.

49. To harden lathe, planer, and similar tools made of high-speed tool steel, they must be heated to a fusing, or white, heat and cooled in air or oil. At a white heat, the steel is very soft and will crumble if struck. It is very necessary to have a non-oxidizing fire, which may be obtained in a covered fire with a large amount of crushed coke over the tuyère, and using a light blast. The steel must not be heated too quickly. When the white heat is attained, a slight fluxing will be observed, and as the heat increases numerous small bubbles will be seen; then the bubbles become larger and fewer in number. If carried to an extreme heat, the steel will soften, a condition

sometimes called *sweating*. On reaching the sweating point, the tools are cooled, usually in a jet of compressed air. One method of doing this is shown in Fig. 34. The tools are placed on an iron plate *a* with a firebrick on either side and a jet of compressed air from a $\frac{3}{8}$-inch pipe *c* is directed against the point of the tool. In order to insure dry air, the air is passed through an iron cylinder *b* about 6 inches in diameter and 3 feet long, the moisture being deposited in the cylinder. The supply pipe *d* is 1 inch in diameter. It is sometimes claimed that with this method the tool is cooled too far back from the point, and that it is therefore better to blow the air upwards against the point *a* of the tool, as shown in Fig. 35.

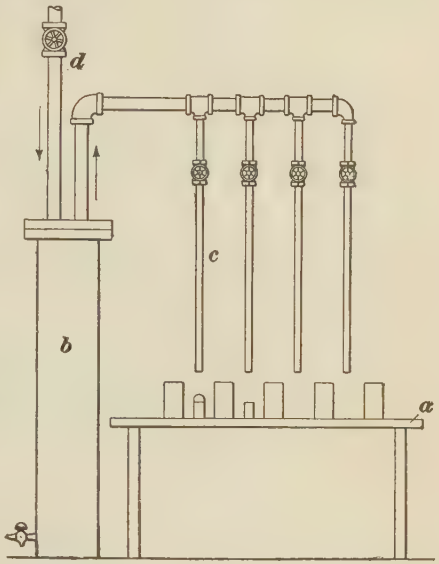


FIG. 34

50. When the tools are oil hardened, all that is necessary is a tank of oil, although in shops where a large amount of hardening is done a large tank that is equipped with a device for cooling and circulating the oil should be provided. One form of oil tank is shown in Fig. 36. It consists of a sheet-iron casing *a*, a removable ring *b* that supports netting *c*, and pipe *d* through which air is supplied to the pipes *e*. The tank is filled with oil to a level indicated by the line *f*, and air under pressure is admitted to the pipes *d* and *e*. These pipes have a number of small holes in their upper sides through

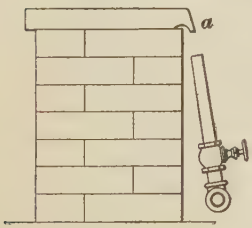


FIG. 35

which the air passes and bubbles up to the surface, thus cooling and circulating the oil. The supply of air is regulated by the valve *g*, and a small net basket *h* may be provided into which small tools may be dropped to quench them, no further attention being required. The netting *c* is used to prevent the tools from dropping to the bottom of the tank.

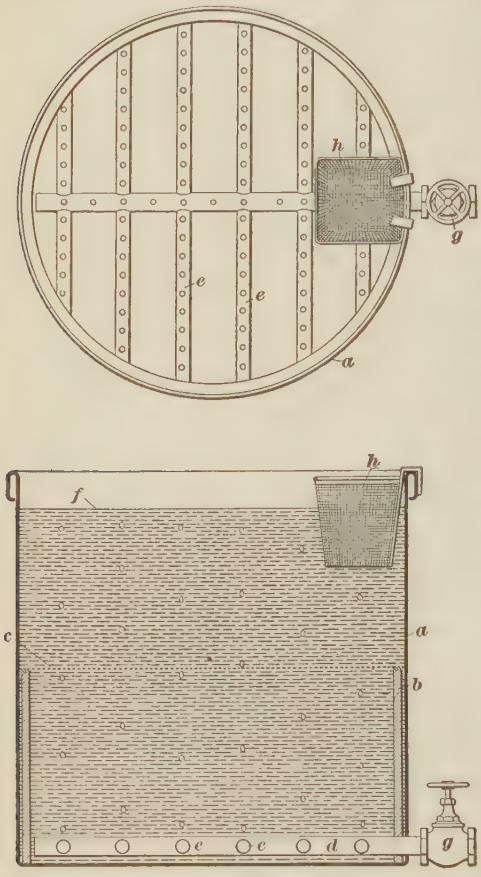


FIG. 36

51. There are many different oils used for the quenching bath, linseed, cottonseed, fish, whale, lard, and kerosene being the most commonly used. Whale and fish oils are probably the best suited for the bath but they have offensive odors. This disadvantage may, however, be overcome by mixing a little heavy mineral oil with them. Linseed oil is inclined to be too gummy for general use, while lard oil becomes rancid in time. When kerosene oil is used, the tools should be plunged quickly to a point above the heated portion in order that there will be no flashing, or burning of the oil. To avoid oxidation, the quenching must be done as soon as possible after the removal of the tool from the furnace.

52. Round-Nosed Lathe Tool.—One form of round-nosed tool used to take roughing cuts when turning is shown in Fig. 37 (*a*) as it appears after the forging is finished. This tool is made of $1'' \times 1\frac{1}{2}''$ bar stock and is known as a 1-inch

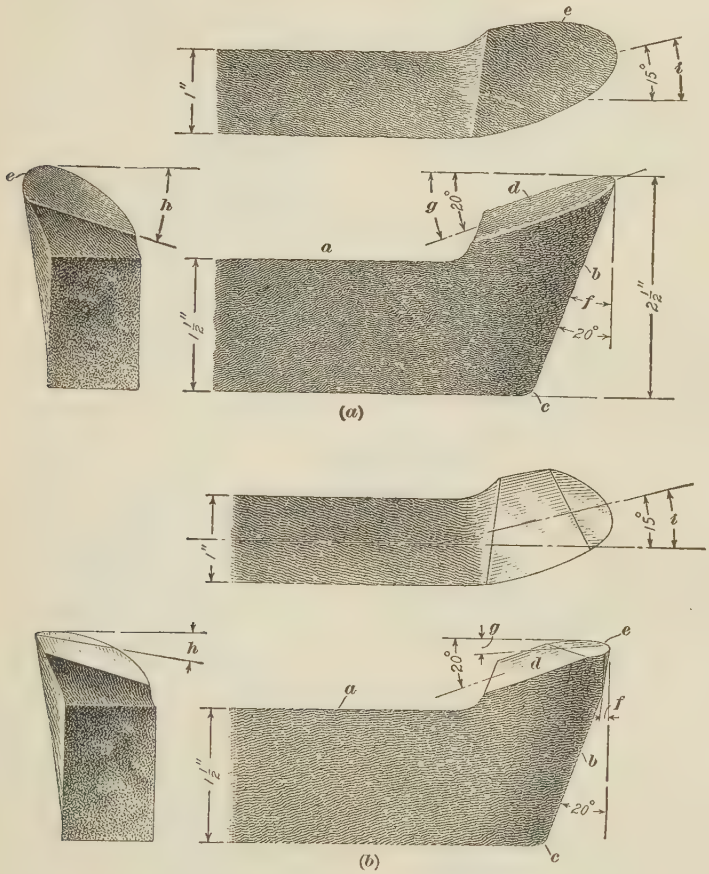


FIG. 37

tool. In (*b*), the tool is shown after it has been hardened and ground ready for use. In the illustrations, *a* represents the body of the tool; *b*, the nose; *c*, the heel; *d*, the lip surface; *e*, the cutting edge; *f*, the clearance angle; *g*, the back slope or top front rake; and *h*, the side slope or top side rake.

The nose of the tool is so forged that the clearance angle, back slope, and side slope will be greater than the corresponding angles of the tool when ground, in order that the amount of metal removed when grinding may be reduced to a minimum; and the nose of the tool is made to extend high above the body of the tool in order that the tool may be reground a large number of times before redressing is necessary. To avoid the tendency of the tool to overturn, or rotate to one side, in the tool post when taking the cut, the nose of the tool is set over to one side of the tool about 15° as shown at *i*.

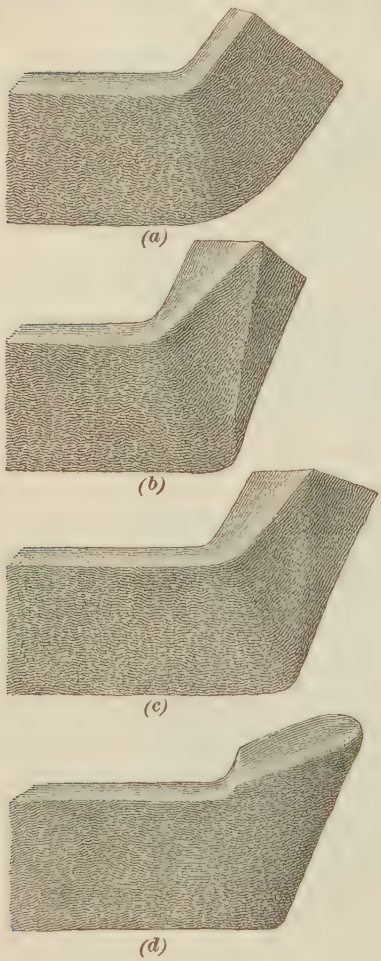


FIG. 38

53. The forging of a round-nosed lathe tool involves heating the end of the stock, bending up the end of the bar to form the nose, drawing down the heel of the tool, shaping the nose with a chisel, cutting the nose to the correct height and lip angle, and setting the nose over to one side. In Fig. 38 (*a*), the stock is shown after the nose has been turned up on the anvil; in (*b*), it is shown with the heel drawn down, to give support close under the cutting edge; in (*c*), the nose is shown cut approximately to the desired shape, the corners shown in (*b*) having been cut off; and in (*d*), the tool is shown cut roughly to the proper lip angle.

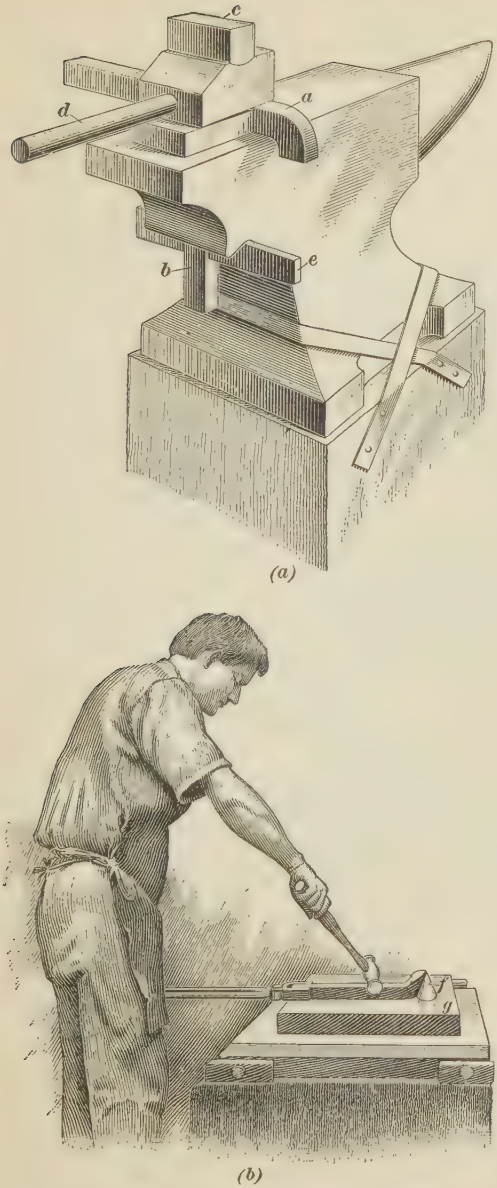


FIG. 39

54. To bend up the end of the bar to form the nose of the tool, the bar may be clamped to the anvil as shown in Fig. 39 (*a*). To do this the heated end of the bar *a* is laid on the face of the anvil so that about 2 inches of the bar extends beyond the edge of the anvil; the shank *b* of the clamp *c* is then passed through the hardie hole, the clamp being held by the handle *d*. The clamp is now drawn tightly against the bar by forcing a wedge *e* into a hole in the shank *b*. The blacksmith and his helper next bend the work to the position shown in the illustration by the use of sledges.

In order to test the angle to which the end of the bar is bent, a gauge similar to that

shown in (*b*) may be mounted near the anvil. This gauge is merely a small cone *f*, in this case having an included angle of 40°, or side angle of 20°, that is fitted into the surface plate *g*. To test the angle to which the end of the bar is bent, the bar is removed from the clamp and placed with its bottom surface on the plate and the bent surface against the cone as shown. If the surfaces of the work and the cone coincide, the end of the bar has been bent to the correct angle. The tool now appears as shown in Fig. 38 (*a*).

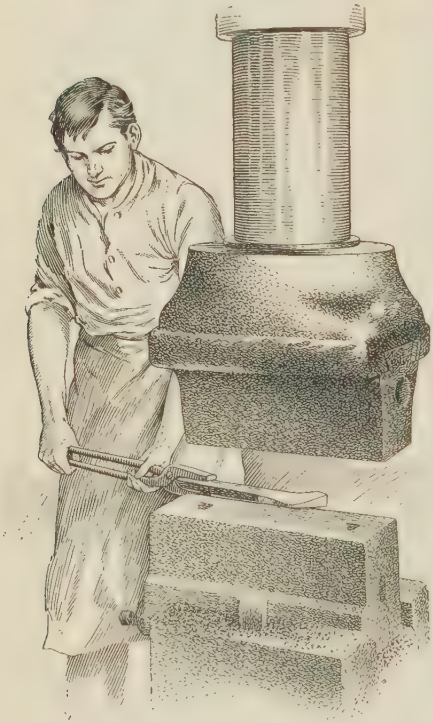
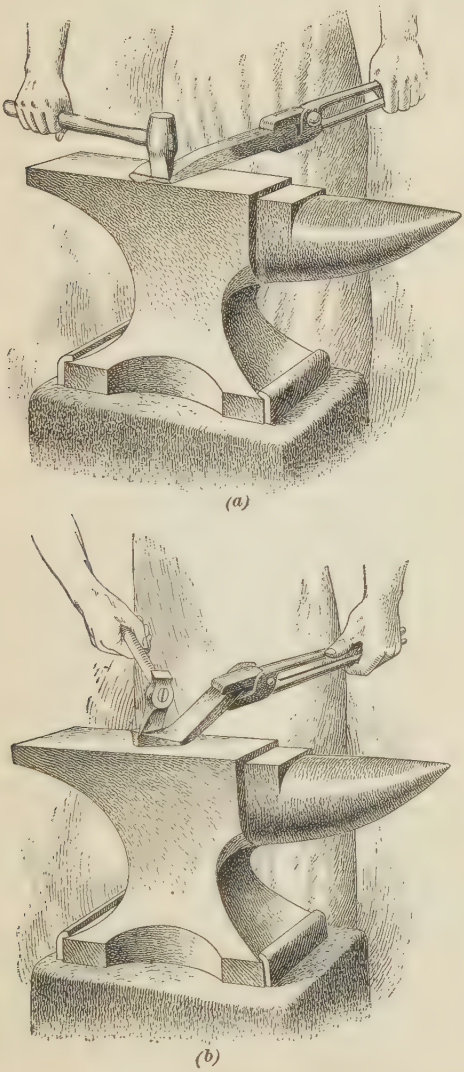


Fig. 40

55. To draw down the heel of the tool to secure a good support under the cutting edge, the tool is quickly released from the clamp, Fig. 39 (*a*), and, without being reheated, removed to a steam hammer. The heel *a* of the tool is then placed on the edge of the anvil, as shown in Fig. 40, and drawn to a wedge shape by a few blows of the hammer. If a power hammer is not available, the heel may be drawn down by sledging upon the anvil. The tool now appears as shown in Fig. 38 (*b*).

56. To make the nose of the tool of the proper curve, it is next laid on the anvil, without being reheated, and its corners are then cut off with a chisel as indicated in Fig. 41 (*a*). The bottom of the heel of the tool is now trimmed off flush with the

bottom of the bar, a chisel mark is made on the nose of the tool to locate the lip surface, and the tool is returned to the fire for a second heat. The tool now appears as shown in Fig. 38 (*c*). All the work done on the tool so far has been in a single heat. In case, however, the tool should become cooled below a light cherry color, it should be reheated before continuing the forging. When reheated, the nose of the tool is cut by the use of a hot chisel as shown in Fig. 41 (*b*) to form the proper lip surface. The tool now appears as shown in Fig. 38 (*d*). The nose of the tool is next bent over sidewise by the use of a flatter, after which it appears as shown in Fig. 37 (*a*).



(*a*)

(*b*)

FIG. 41

57. After the nose is set over, the tool is carefully straightened so that a good bearing surface may be had on the bottom of the tool, the clearance angle is then tested by the use of the cone gauge, as shown in Fig. 39 (*b*), and the

lip surface may be tested by the use of a gauge of the form shown in Fig. 42. To use this gauge, its shank *a* is placed on the body of the tool with the guide *b* against the side of it, the gauge being held by the handle *c* and the part *d* being placed next the lip surface of the tool. The outline of the cutting edge and the angle of the lip surface should be about the same as that of the gauge. The tool is next hardened, after which it is ready to be ground for use.

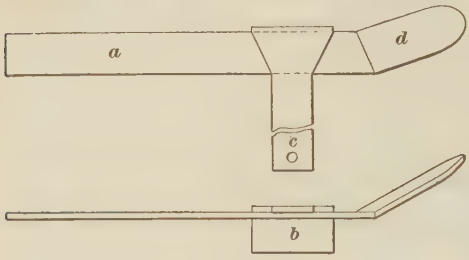


FIG. 42

58. Cutting-Off, or Parting, Tool.—Suppose it is required to forge the cutting-off, or parting, tool, shown in Fig. 43. To make the tool, the end of the stock is first heated to a good forging heat, after which it is held on the anvil as shown in Fig. 44 (*a*) and a fuller mark is made in it by the use of the fuller *a* and the sledge *b*. The tool is next turned over, as shown in (*b*), and it is struck a few blows with the hammer and sledge. It is then turned to the position shown in (*c*) and hammered lightly. The tool is turned back and forth to the positions shown in (*a*), (*b*), and (*c*) while it is being hammered to the required length and thickness. The flat sides and edges of the tool may be finished quickly by the use of a set hammer or flatter, and the final hammering should be done on the cutting edge, or top surface, to smooth the surface so that little grinding will be required.

59. The surplus stock is trimmed off the end of the tool by the use of a hot chisel as shown in Fig. 45 (*a*). The end clearance angle *c*, Fig. 43, may be from 15° to 20°, and a cone *d*, Fig. 45 (*b*), that sets on a surface plate *e* may be used to determine when the required angle is obtained. The end of the

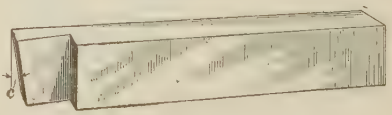


FIG. 43

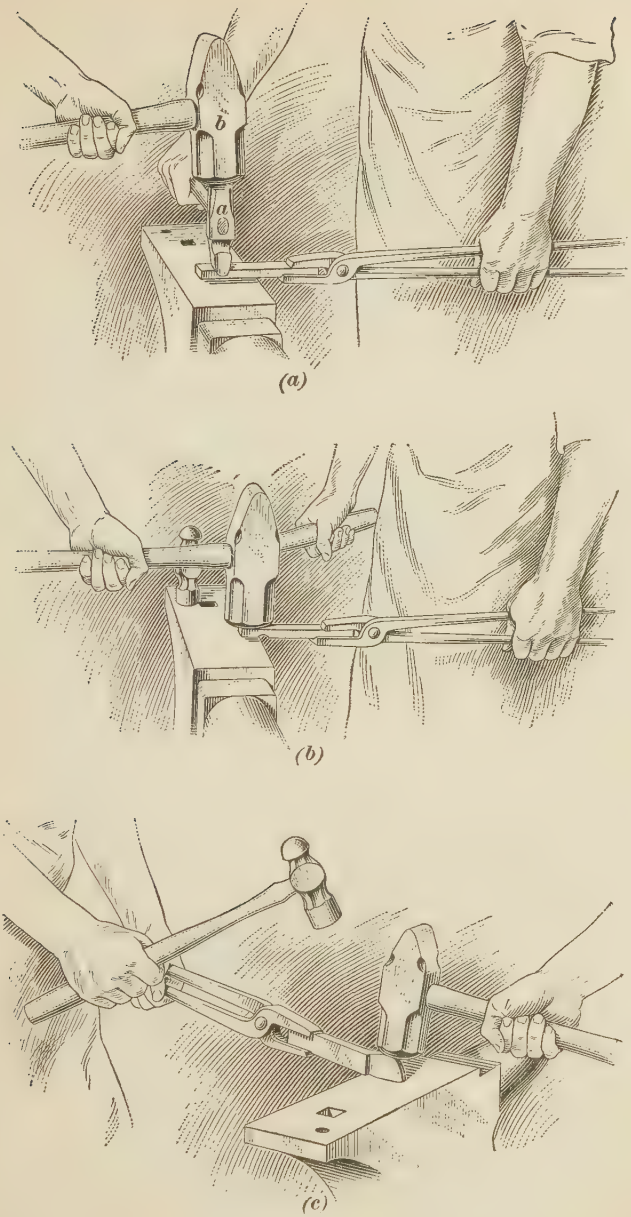


FIG. 44

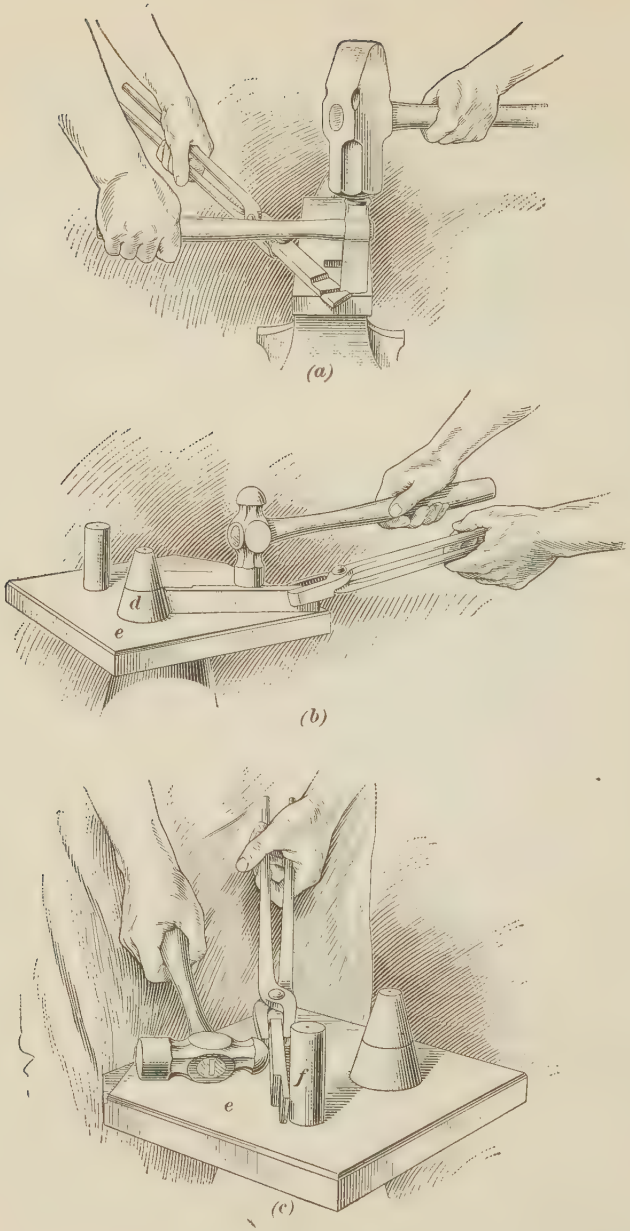


FIG. 45

cutting-off tool must be thinner on its bottom than on its top edge. A convenient way of testing for this is by using a cylindrical gauge *f*, in (*c*), that is fitted to the surface plate *e*. When the corners of the top edge of the tool touch the gauge as shown in the illustration while the corners of the lower edge do not touch it, the tool has side clearance.

60. Other Forged Tools.—The round-nosed tool described is but one form made of high-speed steel. Many other forms are in use. In some cases, the nose is made to extend higher above the body of the tool, and in others the nose does not extend as high. Again, a somewhat different contour of the cutting edge and different clearance and rake angles may be used. The forms of the various tools shown in Figs. 7 to 11 are about the same for high-speed-steel tools as they are for the carbon-steel tools, as far as the forging of them is concerned. The exact shape and dimensions are usually determined by each shop, and a chart and models of the desired forms made. This chart and the models are used by the smith as a guide when forging the tools.

HAMMER WORK

POWER HAMMERS

BEAM POWER HAMMERS

1. A **power hammer** is one that is operated by some mechanical device, and not by a direct-connected steam or compressed air cylinder; those operated by steam or compressed air are called **steam hammers** or **air hammers.** Power hammers are classified, according to the manner of striking the blow, as **helve hammers,** which have very large handles, or *helves;* **trip hammers,** which trip from a cam; and **drop hammers,** which are lifted and allowed to drop.

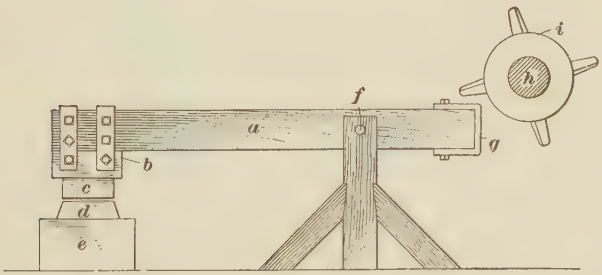


FIG. 1

2. Trip Hammers.—One of the earliest forms of power hammers was the trip hammer with a large helve, as shown in Fig. 1. It consisted of a beam, or helve, *a*, supported near one end by trunnions *f*. The shorter end was covered by a metal strap, or shell, *g*, and to its longer end was attached a weight *b* for a hammer head. To this was keyed the hammer

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face *c*, while the anvil face *d* was keyed to the anvil *e*. A toothed wheel *i* was so mounted on the power shaft *h* that the teeth, or cams, came into contact with the shorter end of the beam and depressed it, thus raising the hammer *b*. As soon as the cam slipped from the beam, the hammer *b* fell and struck the work on the anvil. These hammers were run quite rapidly, yet compared with modern hammers they worked

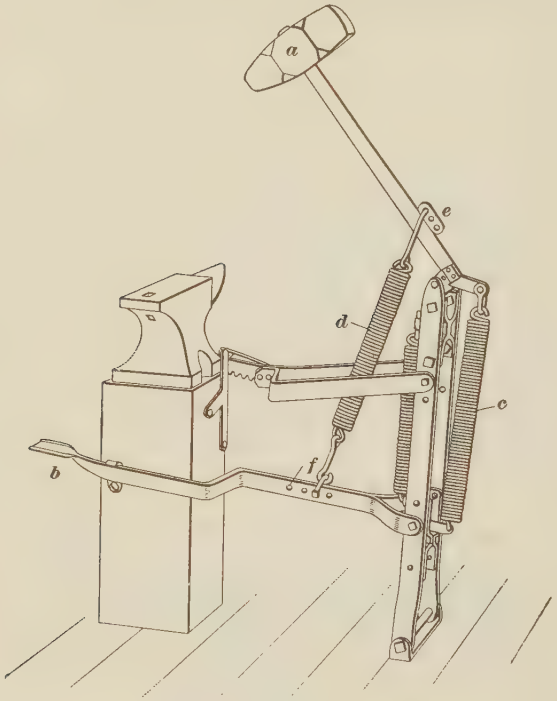

FIG. 2

slowly. The rapid wear of the cam parts, the large floor space occupied, the relatively slow action, and the lack of control have caused this style of hammer to be almost wholly displaced by more modern types.

3. Foot-Operated Hammer.—In small blacksmith shops, it is not always possible to keep a helper for doing the heavy striking, for this work is so intermittent that it would be difficult

to keep the helper busy for the remainder of the time; for this reason the foot-power hammer shown in Fig. 2 was invented. It consists of a heavy sledge *a* hung with a suitable controlling mechanism, of springs and levers, arranged in such a manner that it can be brought down on the work by pressing down the lever *b*. The spring *c* holds the hammer in its upper position, while the spring *d* transmits the pressure of the foot to the hammer handle. The tension in the springs can be regulated by moving the hook to the different holes *e*, or the clevis to the different holes *f*. The position in which the sledge strikes on the face of the anvil can be controlled by a lever near the horn of the anvil, which is not visible in the illustration.

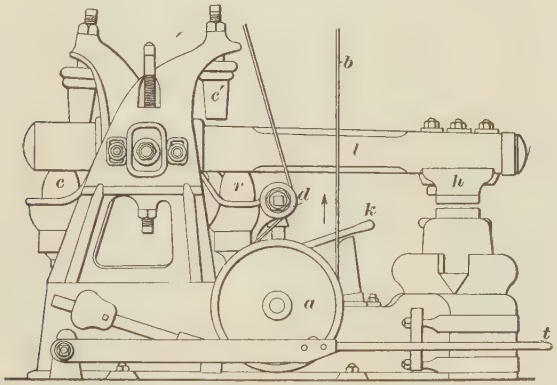

FIG. 3

4. Rubber-Cushioned Helve Hammers.—As the general defects of the trip hammer have long been recognized, the many attempts made to correct them have resulted in a great many types of forging hammers. Where a large number of rapid blows are to be struck on work that is being considerably reduced in size as it is being hammered, some form of elastic support should be provided for the hammer head. A wooden beam has been found to serve this purpose remarkably well, and is used in a great many power hammers; in others, rubber cushions are used. Fig. 3 shows a modern hammer of this class. The beam and hammer resemble those shown in Fig. 1, but the power is transmitted by belt instead of by cams.

In this case, the beam l, carrying the hammer head h, is operated by an eccentric device that moves the rubber cushion r up and down. When the eccentric throws the cushion r up, it raises the right-hand end of the beam, compressing the rubber buffers c and c'. As the eccentric causes the rubber buffer r to descend, the hammer falls not only by its own weight, but also because of the elasticity of the buffers c and c'. The use of these rubber buffers makes the action of the hammer positive and quick, and causes it to do much better work. The position of the hammer head in relation to the anvil is controlled by the lever k, that is, the beam l can be shifted lengthwise by this lever. When the hammer is not in operation, the belt b runs loosely about the pulley a, without causing it to turn. When it is desired to start the hammer, the pressure of the foot on the treadle t brings the tightening pulley d into contact with the belt, taking up the slack and causing the pulley a to turn and operate the hammer. When the treadle t is released, a brake is automatically applied to the driving shaft, and the hammer is instantly stopped. The parts are so arranged that the hammer always stops at the upper point in its stroke.

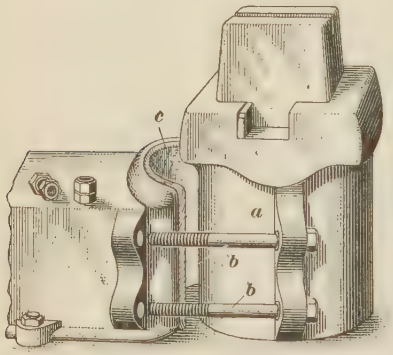

FIG. 4

5. The anvil should be mounted on a separate foundation, so that the continual use of the hammer will not have a tendency to break the frame of the hammer, and also that the upper and lower dies can be kept in line. In the hammer shown in Fig. 3, the anvil is secured to the hammer frame by straps, while bolts through lugs are used in the one shown in Fig. 4, the anvil block a being secured to the frame by bolts b. A layer of packing c, of wood or fiber, is placed between the frame and anvil block and the nuts screwed on and tightened.

GUIDED POWER HAMMERS

6. Upright Helve Hammer.—In order to keep the dies of the hammer in line more perfectly than is possible with the ordinary style of helve hammer, various styles of hammers, in which the hammer dies are guided, have been brought out. In some, wooden helves are used, and the hammers are connected as shown in Fig. 5; in others, steel helves terminate

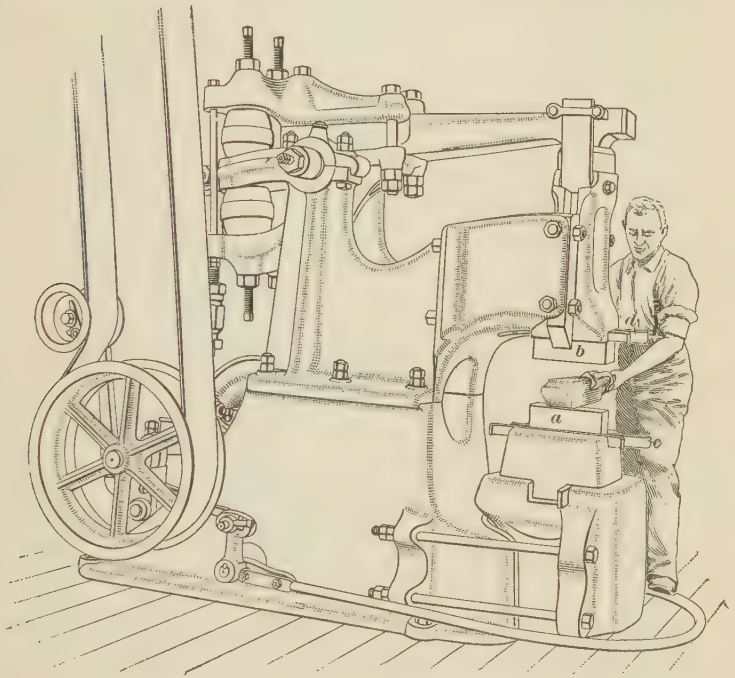

FIG. 5

in bows from which the hammers are hung by straps or by spring connections. The former are called **upright helve hammers,** and the latter **strap hammers.** The strap hammers are especially suitable for the smaller sizes, as they give a very flexible connection, suitable for fast running. In the case of the helve hammer illustrated in Fig. 5, the anvil carrying the lower die is supported on a separate foundation from that which

supports the hammer frame. The hammer dies *a* and *b* are held in place with keys *c* and *d*. The hammer is controlled by

TABLE I

CAPACITY OF RUBBER-CUSHIONED HELVE HAMMERS

Weight of Hammer Pounds	Average Number of Blows per Minute	Average Size of Iron for Which Suited Inches	Approximate Horsepower Required
15	435	$\frac{3}{4}$	$\frac{1}{2}$ to $\frac{3}{4}$
25	400	1	$\frac{3}{4}$ to 1
40	300 to 315	$1\frac{1}{4}$	$1\frac{1}{2}$ to 2
60	290 to 300	$1\frac{3}{4}$	2 to $2\frac{1}{2}$
80	275	2	$2\frac{1}{2}$ to 3
100	275	$2\frac{1}{2}$	$2\frac{1}{2}$ to 3
200	225 to 240	$3\frac{1}{2}$ to 4	3 to $3\frac{1}{2}$

TABLE II

CAPACITY OF CUSHIONED UPRIGHT HELVE HAMMERS AND STRAP HAMMERS

Weight of Upright Hammer Pounds	Style of Upright Hammer	Average Number Blows per Minute	Average Size of Iron for Which Suited Inches	Approximate Horsepower Required
15	Strap hammer	400	$\frac{5}{8}$ to $\frac{3}{4}$	$\frac{1}{2}$ to $\frac{3}{4}$
30	Strap hammer	350 to 375	1	$\frac{3}{4}$ to 1
50	Strap or helve hammer	300 to 315	$1\frac{1}{4}$	$1\frac{1}{2}$ to 2
75	Strap or helve hammer	300 to 315	$1\frac{1}{2}$	$1\frac{1}{2}$ to 2
100	Strap or helve hammer	275 to 300	$1\frac{3}{4}$	2 to $2\frac{1}{2}$
125	Strap or helve hammer	275 to 300	2	2 to $2\frac{1}{2}$
150	Strap or helve hammer	250 to 275	$2\frac{1}{2}$	$2\frac{1}{2}$ to 3
200	Strap or helve hammer	200 to 225	3	3 to $3\frac{1}{2}$
300	Helve hammer	175 to 190	$3\frac{1}{2}$ to 4	$3\frac{1}{2}$ to 4
500	Helve hammer	150 to 175	4 to 5	5 to 6

a loose belt and tightener, and the parts are so arranged that the hammer always comes to rest at the top of its stroke.

The power required by, and the capacities of, these hammers, as given by one manufacturer, are shown in Tables I and II. Table I is for rubber-cushioned helve hammers, and Table II for cushioned upright helve hammers and strap ham-

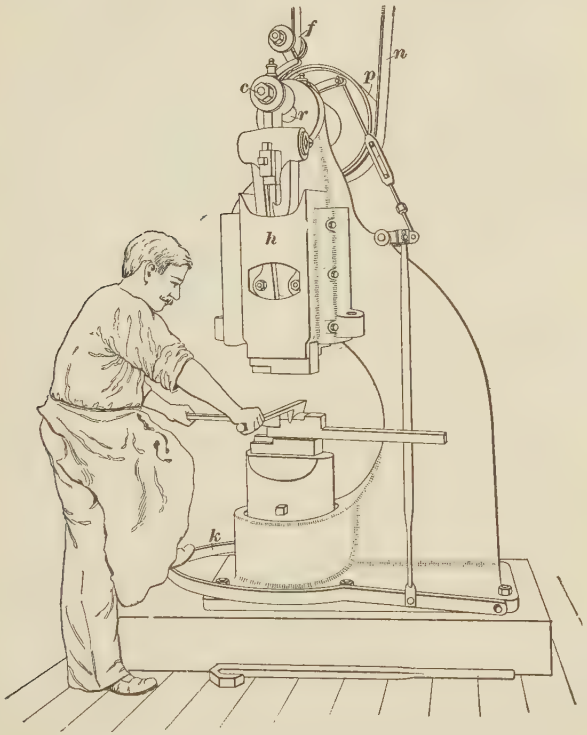

FIG. 6

mers. The sizes given for iron should be reduced one-third when applied to steel. These sizes are only approximate, as any hammer will do both larger and smaller work; they are, however, the sizes for which each hammer is especially suitable for continuous service.

7. Forging Hammers.—A somewhat different type of forging hammer is shown in Fig. 6. In this class, the operating

mechanism is all at the top, but the hammer is started and stopped by shifting the tightening pulley *f*, which is connected with a foot-treadle *k*; when the hammer is not in use, the belt *n* runs loose about the pulley *p* without causing it to turn, and is thrown into action by the pulley *f*, which takes up the slack in the belt. The length of stroke of the hammer can be adjusted by shifting the crank-pin *c* in the slot *r* of the crank. In the style shown, the hammer frame surrounds the anvil, so that the latter may be provided with a separate foundation, as explained in Art. **5**, and still be held in line with the hammer head *h*.

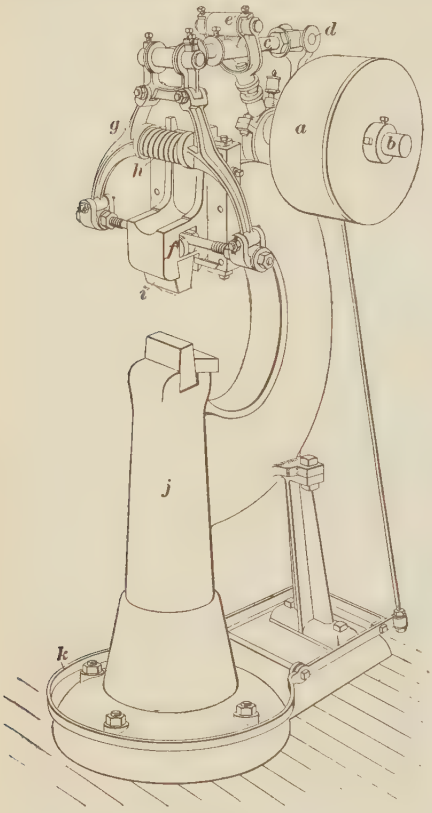

FIG. 7

8. A helve hammer suitable for light forging is shown in Fig. 7. Power is applied by means of a belt running over the pulley *a*. This pulley ordinarily runs loose on the shaft *b*, but the shaft may be driven by the pulley through a clutch. The helve *c* is pivoted to the frame at *d* and is driven by means of an eccentric on the end of the shaft *b* and a connecting-rod that is attached to the center casting *e* on the helve. The ram *f* is suspended from the outer end of the helve by the yoke *g*. This yoke is made so that, when the ram strikes the work, the side pieces are drawn together against the coil spring *h* and the eccentric that drives the helve can rotate, even when thick

stock is being hammered without overstraining any part of the hammer. The ram *f* moves vertically in guides on the frame so that the face of the upper die *i* is always parallel to the lower die. The anvil *j* is heavy enough to absorb the force of the blow since it is a part of the frame that may be broken if the anvil is too light. The clutch through which the shaft *b* is driven is engaged by pressing on the treadle *k*, and releasing the treadle automatically releases the clutch.

POWER-HAMMER WORK

9. Breaking Down.—Power hammers are frequently used for the heavy roughing or breaking down of work that is finished under a drop hammer. In many cases, this breaking down

TABLE III
SPEED AND SIZE OF STOCK FOR POWER HAMMERS

Weight of Ram Pounds	Speed Blows per Minute	Size of Stock Inches Square
25	475	$1\frac{1}{2}$
50	450	$1\frac{3}{4}$
75	425	2
100	400	$2\frac{1}{4}$
125	375	$2\frac{1}{2}$
150	350	3
200	325	$3\frac{1}{4}$

can be done between flat dies, as in the hammer shown in Fig. 5, while in other cases it is better to use dies with convex or curved faces, as shown in Fig. 7, which act like fullers. If the work is round, it is turned slightly after each blow of the hammer. Rectangular work is also frequently drawn to a taper, between either plane or curved dies.

Power hammers usually work much more rapidly than do steam and drop hammers, and power hammers will therefore forge much larger material in proportion to their size than will the slower acting hammers. The speed at which a hammer

may be run and the size of stock that can be economically forged on it depend largely on the skill of the operator, but if a hammer is forging stock that is too large for it to work to advantage, the amount of reduction at each blow will be so small that the stock will have to be reheated a number of times before the work can be finished. Table III gives the approximate size of square stock that can be worked with economy on power hammers of various sizes and the speed at which the hammers may be run, but the speed of any particular hammer and the size of stock that it will work economically may differ for one reason or another from the value given in the table. Any power hammer will work smaller stock than that given, and it will work round stock about one-fourth larger than the regular stock indicated. Power hammers will be found useful for work in an ordinary jobbing shop, or for tool dressing.

STEAM AND AIR HAMMERS

10. The hammer shown in Fig. 8 is driven by compressed air supplied by a compressor contained within the hammer frame. In this case, the compressor is driven by an electric motor *a* that operates a plunger in the compressor cylinder *b*. The air compressed in the cylinder *b* goes through passages in the frame to the ram cylinder *c* in which a piston on the end of the ram *d* works. The working of the hammer, when the motor is running, is controlled by valves that are operated either by the hand lever *e* or the treadle *f*. The valves may be set so that the ram will remain at the top of its stroke, strike blows of any intensity within the capacity of the hammer, or grip the stock between the upper and lower dies like a vise.

11. Steam Forging Hammer.—There is a large variety of steam forging hammers, as different styles have been designed to meet different conditions. In Fig. 9, the hammer head *a* carries the upper die *b*, which strikes the die *c* keyed to the anvil *d*. The hammer head *a* is keyed to the rod *e*, which is connected to a piston working in the cylinder *f*. Steam may be admitted to the cylinder, either above or below the piston, by a suitable valve mechanism controlled by the lever *g*. The

lever *k* operates a throttle valve for shutting off the steam from the controlling valve when the hammer is not in use. When steam is admitted below the piston, the piston and the hammer are raised. The blow can then be struck by simply allowing the steam to exhaust and the hammer to fall. A very much

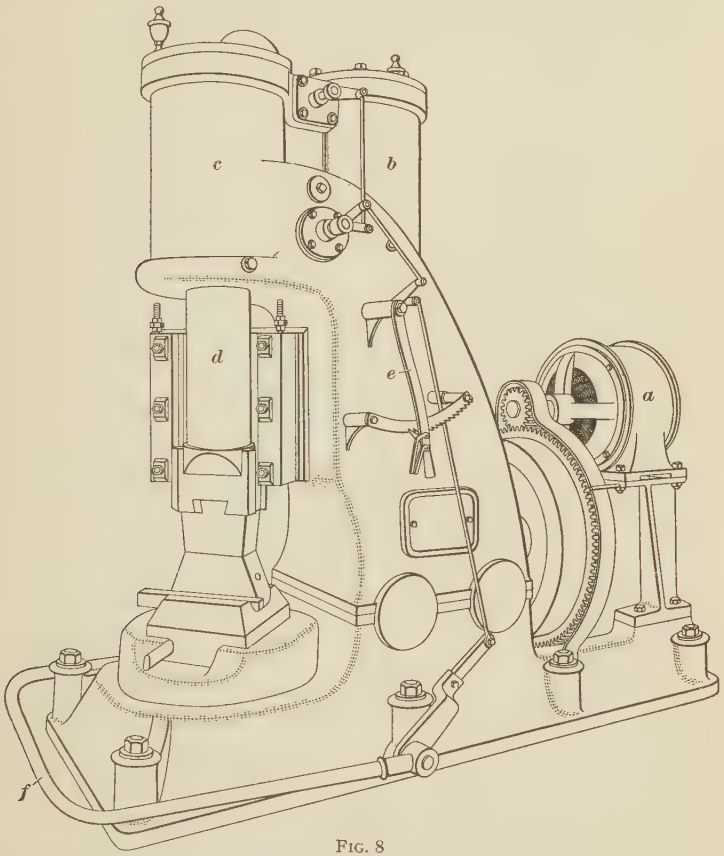

FIG. 8

harder blow can be struck by admitting steam above the piston to drive it down. The steam also starts the piston more quickly, and more rapid blows may be struck.

Among the special advantages of the steam forging hammer are the small floor space occupied for a given capacity

as compared with the helve hammer, and the better control of the blows, and the position of the dies in relation to each other. When the steam forging hammer is not in use, the hammer head descends and rests on the lower die.

12. Steam-Hammer Valves.—In steam hammers, it is customary to supply a throttle valve at the point where the steam enters the valve chest, and a controlling valve for admitting steam to both sides of the piston; this controlling valve is usually some type of slide valve, but a rotating valve is sometimes used. One arrangement of the valves is shown in Fig. 10. The throttle valve *a* for shutting off the steam is operated by the lever *k*, Fig. 9. The controlling valve in this case is a hollow piston valve *b*, Fig. 10, around which the steam passes to the ports *c* and *d*, and through which the exhaust steam from the port *c* passes to reach the exhaust passage *e*.

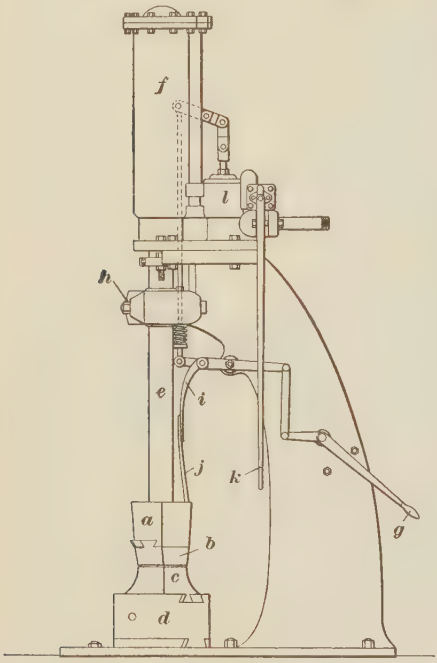

FIG. 9

In the position shown, steam is entering through the throttle *a*, passing around the controlling valve *b*, filling the passage *f* that surrounds the valve, and passing through the lower port *d*, as shown by the arrows, into the cylinder beneath the piston. At the same time, the steam on top of the piston is exhausting from the cylinder through the port *c*, which connects with the top of the cylinder, through the center of the valve *b* and out the exhaust passage *e*, as shown by the arrows. The

hammer will, therefore, rise until the piston reaches the top of the stroke, unless the valve *b* is raised to close the passage of the steam to the port *d*. To force the hammer down, the controlling valve must be moved so that steam will pass from *f* through *c* to the top of the cylinder, and steam from the other end will exhaust through the exhaust passage to the outer air.

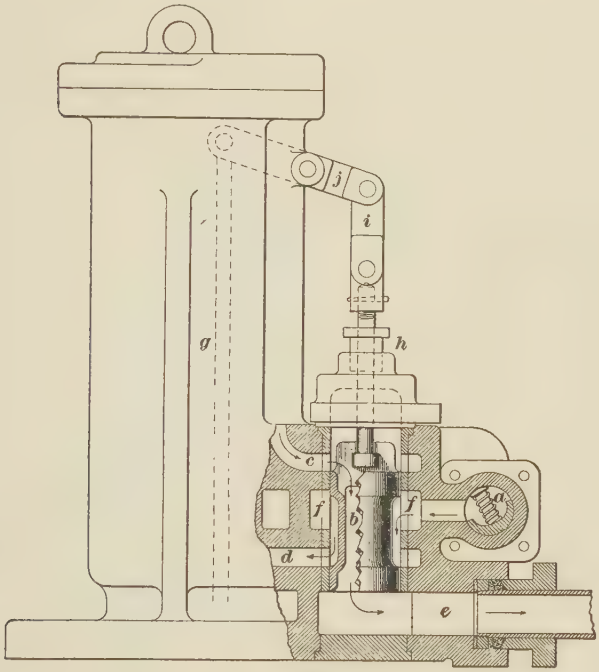

Fig. 10

The rod *g*, shown dotted behind the cylinder, is attached to the lever *j* and, with link *i*, shifts the valve stem and valve. The valve stem passes through a stuffingbox *h*, which prevents steam from leaking out around the stem. The rod shown behind the cylinder in Fig. 9 moves the valve, and is operated through links, as shown, by the lever *g*. In this case, the rod is lowered in order to raise the controlling valve in the valve chest *l*, the arrangement being very much like that shown in Fig. 10.

13. Control of Steam Hammers.—Steam hammers are controlled either by hand or by automatic controlling mechanisms. The hammer shown in Fig. 9 may be controlled by the lever *g*; or it may be controlled automatically by means of cam *i*, which comes in contact with the inclined piece *j* on the hammer head. This cam operates the valve mechanism and reverses the hammer for another stroke. A mechanism of this kind enables the operator to make the hammer strike a series of uniformly light or heavy blows as the case may require, thus operating the hammer automatically. In the position shown in Fig. 9, the valve is down and steam is entering below the piston; as the piston rises, the inclined piece *j* will force the cam *i* to one side and reverse the valve, causing the hammer to strike. As the hammer comes down, the cam *i* will be moved back so as to raise the rod behind the cylinder, causing the valve to lower and thus admit steam below the piston to raise the hammer.

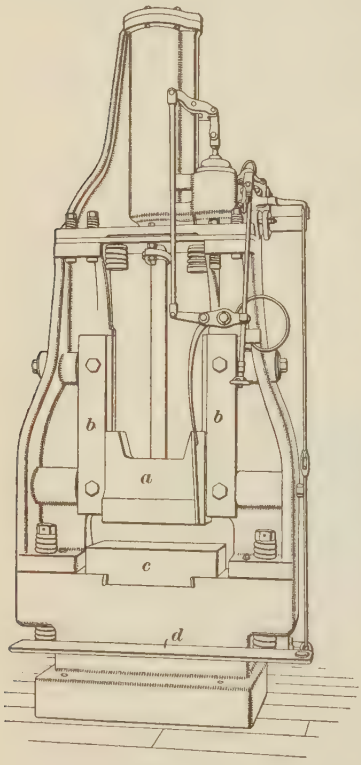

FIG. 11

14. Steam Drop Hammer. One form of steam drop hammer is shown in Fig. 11. This hammer differs from the steam forge hammer in that the head *a* moves between adjustable guides *b*. Another point of difference is that the anvil *c* and the frame of the hammer are on the same foundation; in fact, the anvil supports the frame. The steam is used for raising the hammer head, which does its work by falling, as in the case of the ordinary drop hammer. For this reason,

the name steam drop hammer has been applied to this type of hammer, although provision is made in the best hammers by which steam can be used above the piston to increase the force of the blow. The piston is always under control by the foot-treadle *d*, which stands across the front of the machine.

When the steam drop hammer is not in use, the mechanism automatically raises the hammer head and holds it in its high-

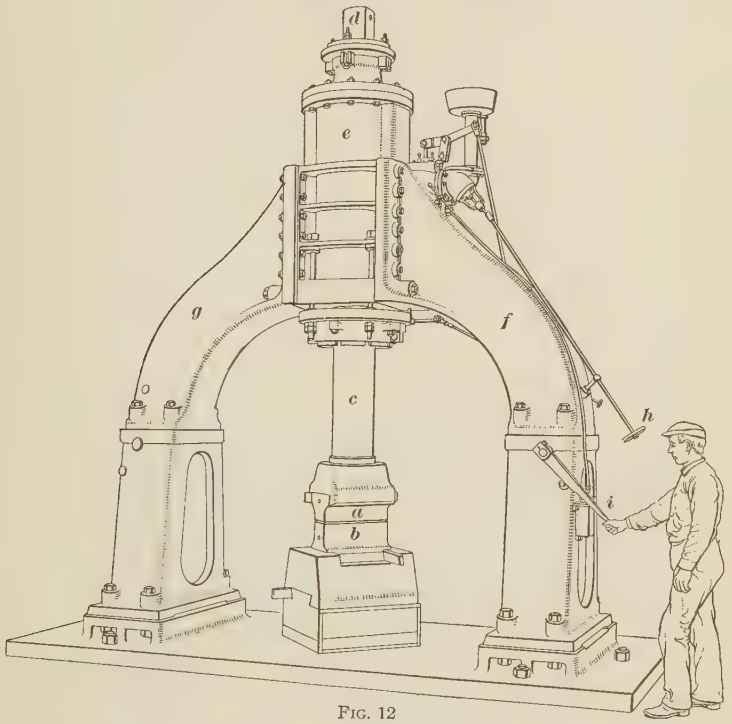

FIG. 12

est position. Such a hammer may be fitted with suitable dies and used for forging operations, but as a rule it is not so well adapted to this work as the regular steam forging hammer.

15. Types of Hammer Frames.—In forging, the hammers commonly used are divided into two classes, known as *single-* and *double-frame hammers*. The single-frame type, Fig. 9, is best for small or light work because there is only one

standard or leg to interfere with bringing the work to the hammer dies, and with moving the work about while forging. As a rule, double frames, Fig. 12, are used only on the larger sizes

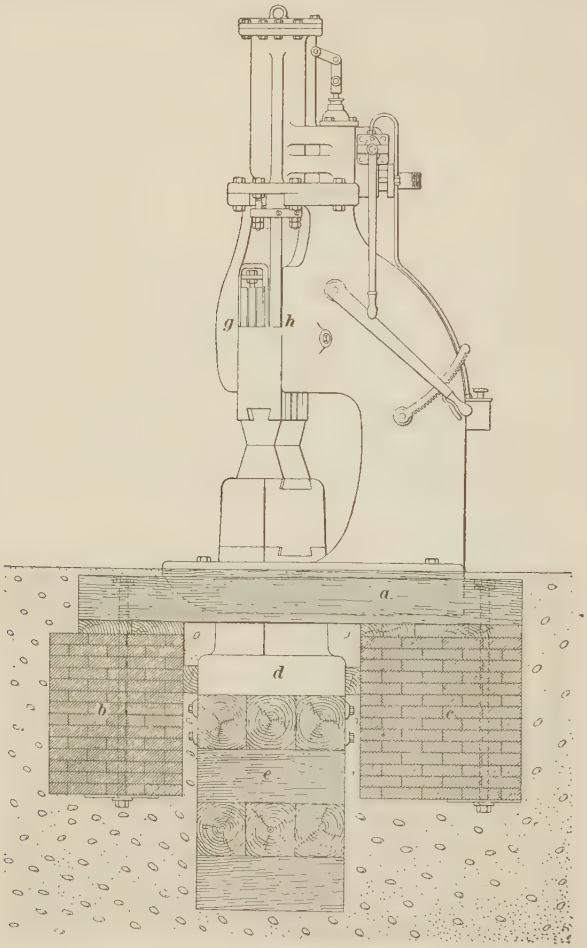

FIG. 13

of forging hammers, and ample space is usually left about the anvil to permit the introduction of both the work and the tools. In both the single- and double-frame hammers the dies are generally set at an angle of 45° to the frame, as shown

at *b* and *c*, Fig. 9, and *a* and *b*, Fig. 12. Setting the dies at 45° to the face of the frame permits long work to be placed either across the dies or along their length, and allows the work to be handled under the hammer without striking the frame. It also permits the use of hand tools, which are placed on top and at right angles to the work, without serious interference by the frame.

In the hammer shown in Fig. 12, the steam cylinder *e* is a separate casting that is bolted on opposite sides to the side frames *f* and *g*. The piston has an upper rod, or tailrod, *d*, which is flat on one side to prevent the piston and hammer from turning. There is no foot-lever for operating this hammer; the hand wheel *h* is attached to the rod that moves the throttle valve, and the lever *i* is connected to the valve that controls the admission of steam to, and the exhaust from, the cylinder.

16. Hammer Guides.—In the case of steam hammers, it is necessary to provide some form of guide that will keep the upper and lower dies in line. There are two types of guides in common use. In one type, the piston rod is made of comparatively small diameter, and the weight is concentrated in the hammer head, as shown at *a* in the steam drop hammer, Fig. 11. The hammer head is guided independently of the piston in the cylinder by guides *b* located below the cylinder. In the single-frame forging hammer shown in Fig. 9, a short guide is provided at *h*; while in the hammer shown in Fig. 13, the hammer head is guided between the overhanging portions *g* and *h* of the frame.

The other type of guide is that in which the cylinder heads act as the guides, as shown in Fig. 12. This style of hammer is known as the *Morrison* type, after the name of its inventor. The weight, instead of being concentrated in the hammer head, is distributed in the hammer and in the long bar or piston rod *c*. Guides are provided in the upper and lower cylinder heads; and as these guides are a considerable distance apart it is possible to line up the dies very accurately. The relatively large diameter of the bar that forms the piston rod makes it

very strong, so that very heavy blows may be struck without danger of breaking or springing it.

17. Proper Weight of Hammer.—When wrought iron was the only material worked under the steam hammer, it was not so necessary to provide heavy hammers, as the forgings were built up by welding a large number of thin slabs together, which were affected clear through by blows from a relatively light hammer. During this building-up process, all the metal in the forging was thoroughly worked. The metal also had been subjected to considerable hammering to produce the slabs from which the forging was built up; this hammering tended to produce a forging of good quality. The introduction of steel forgings developed an entirely new set of conditions. The structure of steel differs from that of wrought iron, and it requires much more work to produce a given effect on a piece of steel, so that for a given thickness of metal a heavier hammer is required. In making steel forgings, it is necessary also to work them down from relatively large billets, and a large enough mass must be taken to produce the finished forging.

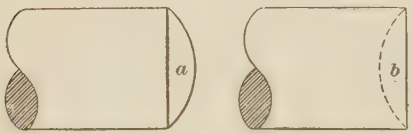

FIG. 14

On large forgings, therefore, it is necessary to use a large billet and a heavy enough hammer, so that the blow will penetrate to the center of the work. If a sufficiently heavy hammer is used, and the center of the piece receives a sufficient amount of working, the end of the forging will be convex, as shown at *a*, Fig. 14. If the hammer is too light for the forging, the blows will only affect the outer surface of the metal, stretching it and causing the ends to be dished, or concave, as shown at *b*. When the surface metal is stretched in this way, it has a tendency to tear away from the inside metal, forming a series of cracks, and in some cases openings of considerable size. If the hammer is not heavy enough, therefore, to make the ends of the work assume the form shown at *a*, it is too light for the piece being forged, and only poor results can be expected.

18. Hammer Foundations.—In most cases, steam-hammer manufacturers recommend the placing of the anvil and the hammer on separate foundations. A foundation for

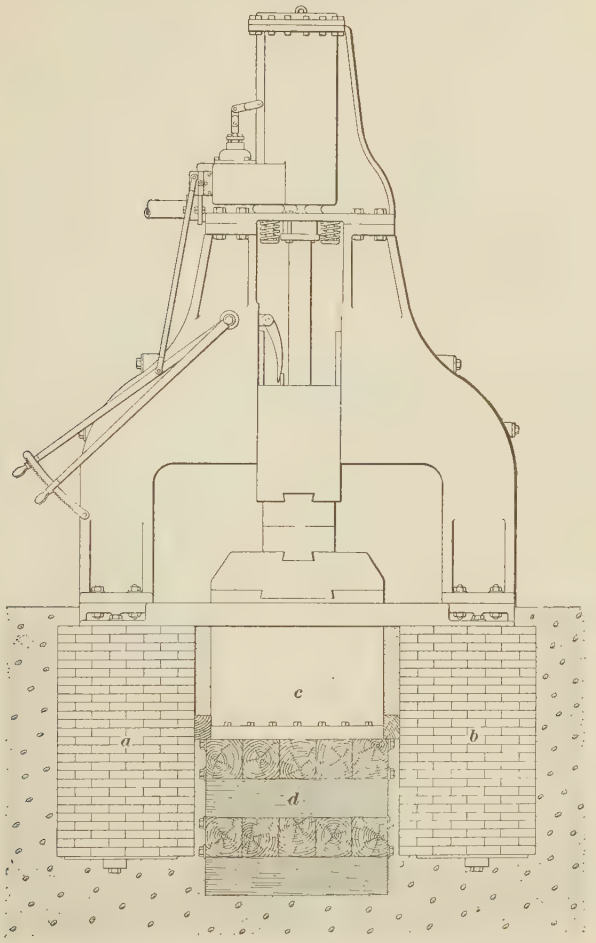

FIG. 15

a single-frame hammer is shown in Fig. 13. The frame of the hammer is supported on timbers *a*, carried on brick piers *b* and *c*. Between these brick piers is arranged a timber foundation *e*, on which the anvil block *d* is mounted. A foundation

for a double-frame hammer is shown in Fig. 15. In this case the frame of the hammer is supported on two piers *a* and *b*, while the anvil block *c* is supported on the timber foundation *d*.

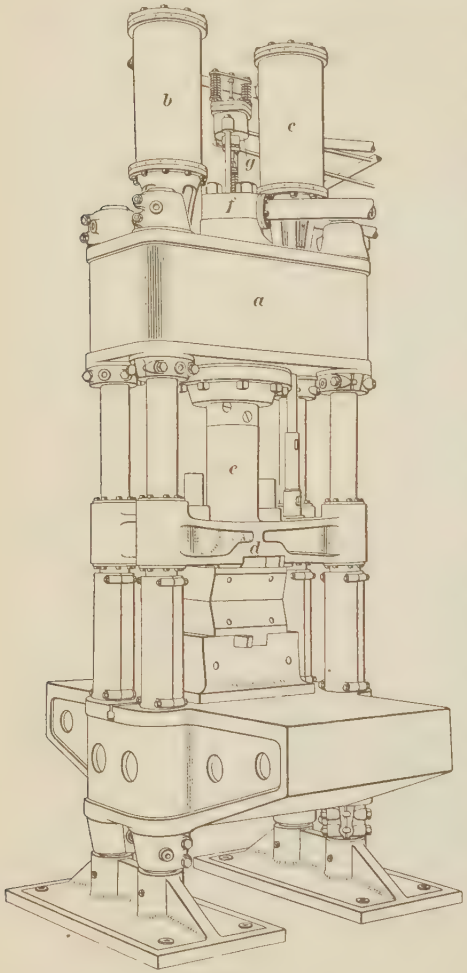

Fig. 16

Recently, some manufacturers have advocated the use of rigid concrete foundations for both the hammer and the anvil. This construction necessitates the use of very much heavier anvil blocks and hammer frames, but it makes the blows of the hammer more effective, as the work absorbs all the energy of the blow instead of having a portion dissipated owing to the spring of the anvil. There is one advantage, however, in favor of wooden or elastic foundations, the slight yielding causes the work of the blow to be distributed over a longer interval of time than on a solid foundation. This slower action permits the force of the blow to penetrate deeper, thus working the metal more thoroughly than when the anvil is set on a solid foundation. Sufficient elasticity to allow the effect of the blow to penetrate to the center of the work is necessary for forging steel.

HYDRAULIC FORGING PRESS

19. The hydraulic forging press shown in Fig. 16 does much the same work as steam hammers, but it acts on the work by pressure instead of by blows. There are three hydraulic cylinders *a*, *b*, and *c*, each containing a single-acting piston. The pistons in *b* and *c* act on the upward stroke and lift the crosshead *d* and upper die, and the piston in *a* acts on the downward stroke and works the stock between the dies. The large size of the piston in *a*, together with the high-water pressure that is applied to it, produces the working pressure on the dies. A press of this type, capable of exerting a pressure of 30,000,000 pounds on the upper die, has been built. The flow of water to and from the working cylinder is controlled by the valve *f* through water pressure in the cylinder *g*.

When the press is in action, the upper die is brought down on the work and pressure is applied, thus squeezing the work into the desired shape. The work is, however, not brought to the finished shape by pressure continuously applied, but by a series of squeezes that knead the stock thoroughly. The pressure being applied gradually, allows time for the kneading effect to penetrate more uniformly to all parts of the material than when the working is done by a series of heavy blows, and it permits the forging of large pieces that would be difficult to handle under a steam hammer.

HAMMER TOOLS

20. Porter Bars.—In welding up large shafting from scrap it is necessary to have a starting piece, so that the forging can be handled to advantage. The starting piece for forging a shaft is called a **porter bar**, Fig. 17, and consists of a short section of shafting of about the same diameter as the desired shaft, to which pieces may be welded to form the shaft. One end *a* is forged to a shovel shape to receive the bars or stock to be welded on. Where iron shafts of different diameters or other iron forgings are being made, several sizes of porter bars are always kept on hand.

21. Stocks.—For turning and handling the porter bar or the entire forging, **stocks** *b*, Fig. 17, are employed; they are shown in greater detail in Fig. 18. Two such stocks are generally used, being held together by bolts passing through the

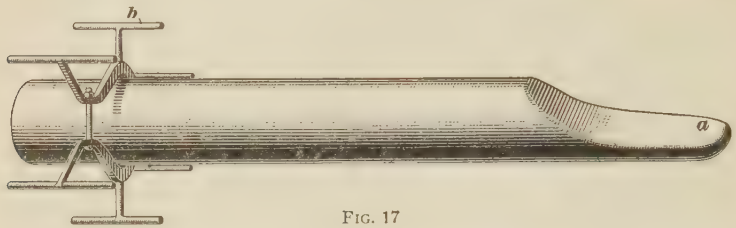

FIG. 17

holes *a*. The handles *b*, *c*, and *d* are so arranged that when the stocks are clamped to the work as shown in Fig. 17, the six handles of the two stocks will be located at approximately equal distances apart, around the work. For handling square work, a stock of the form shown in Fig. 19 is frequently used.

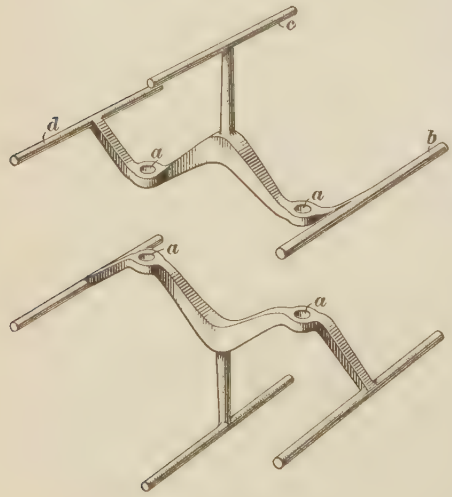

FIG. 18

22. Hacks or Cutters.—A **hack** is used for cutting off hot work under either steam or power hammers. The ordinary blacksmiths' hot chisel is not suitable for such work, as it is too high and slender. The general form of the hack is shown at *a*, Fig. 20 (*a*). The cutting edge is not as sharp as that of the ordinary hot chisel, and the tool must be held nearly vertical when struck with the hammer. When it is in an inclined position, as shown in (*b*), the hammer is liable to knock the hack over on its side and bed it into the work, possibly ruining the

piece. When it is desired to form a square shoulder, the hack must be held with one side vertical, as shown in (*c*), but when it is desired to cut the work in two to form separate billets or pieces of metal, the hack is driven straight down, as

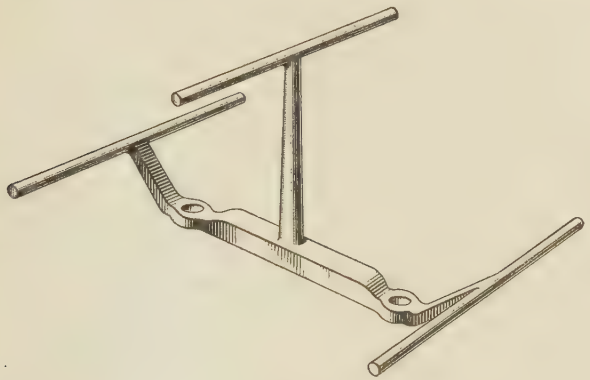

FIG. 19

shown in (*d*). The hack is driven nearly through the piece from one side, the piece is then turned over, as shown in (*e*), and a small bar, equal in width to the flat end of the cutter is placed as shown at *f* and driven through with a single sharp

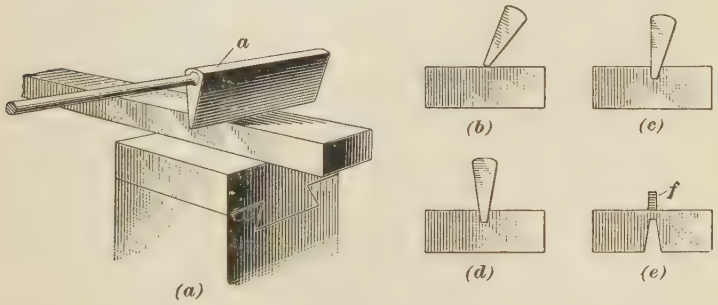

FIG. 20

blow of the hammer. This cuts out a core, equal in width to the bar *f*, and so avoids the formation of a fin on either piece. Such a fin would be very objectionable at a weld, as it would probably cause a defect in the forging where the weld was made.

23. For marking the work at points from which it is to be drawn down, that is, for marking shoulders, a piece of round iron of small diameter is frequently driven in by the hammer as the stock is slowly rotated. Frequently a bar of square iron is used for shouldering down work, but this method leaves a sharp corner at the bottom, which is liable to cause a defect during the subsequent forging operations.

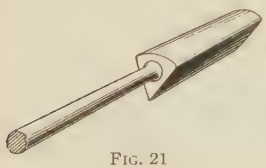

FIG. 21

For nicking work cold under the hammer, a cold chisel of the form shown in Fig. 21 is frequently used. It consists of a blunt triangular piece of steel that is hardened and tempered; it usually has a round handle of steel or iron forged to it, and the back of the chisel is somewhat round, as shown in the illustration.

24. Swages.—Sometimes ordinary two-part **swages** are used for small hammer work, the upper swage being fitted with a handle, as shown in Fig. 22 (*a*). Frequently, the handle is drawn down flat near the swage, as shown at *a*, so as to allow it to spring and thus avoid stinging the hands of the man holding it. When a bottom swage is made to go with a top swage, it may be provided with projections or lugs, shown in (*b*), to hook over the face of the anvil. In most cases, if there are two projections on one side there is only one projection on the other side.

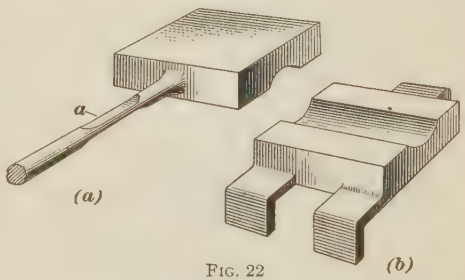

FIG. 22

25. In other cases, the top and bottom swages are connected. Fig. 23 (*a*) shows a form in which the handles of the swage are made from 1-inch round steel with a spring at the end *b*, made from $\frac{3}{8}'' \times 2''$ stock. The handles *a* in this case are about 42 inches long. The spring *b* serves to keep the two parts of the swage separate at all times. Another type

of swage is shown in (*b*). In this case, the handles *a* are about 4 feet long, and are made of $\frac{1}{2}'' \times 2''$ steel; they are secured together at the end by a band *b* and the rivet *c*. In other cases, two rivets are used in place of the band and rivet; and

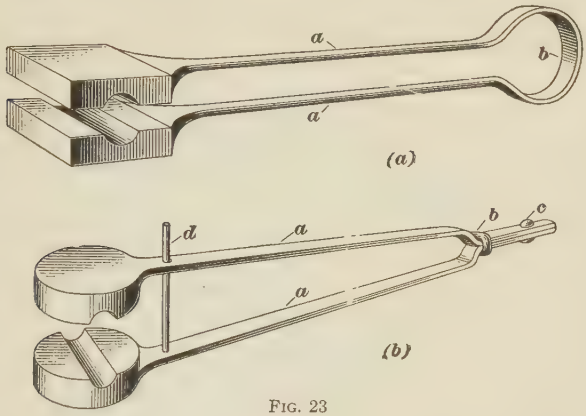

FIG. 23

sometimes, to hold the two parts in line, a small pin about $\frac{1}{2}$ inch in diameter is passed through a hole in the upper handle, as shown at *d*, the hole being at least $\frac{1}{32}$ inch larger in diameter than the pin. The pin is fastened securely in the lower handle either by tapping and screwing it in, or by locknuts on top and bottom. These guide pins are quite necessary in the case of swages that are to do fairly accurate work.

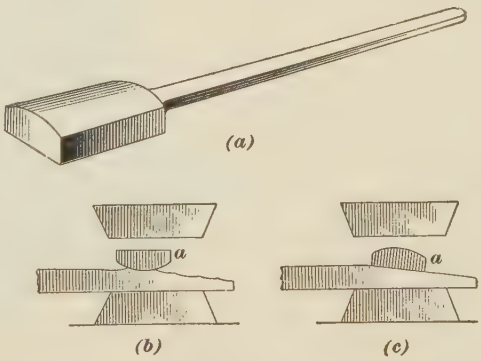

FIG. 24

26. A fuller of the form shown in Fig. 24 (*a*) is frequently used for drawing work to a taper under the hammer. The fuller is held, while drawing down the work, as shown at *a*, in (*b*); but for smoothing the work, it is turned over and used as shown at *a*, in (*c*).

Distance, or gauge, blocks are rectangular blocks of iron or steel that are used to determine when stock has been reduced to the desired dimensions. Gauge blocks are usually provided with handles so that the workman can place the one that is of the proper thickness on the anvil beside the work and hold it there until the hammer strikes the block.

27. Dies for Steam Hammers.—There are two dies for a steam hammer. One of these is fastened to the ram and the other to the anvil. The shape of these dies and the material of which they are made are determined by the work they have to do. For ordinary forging, flat dies are commonly used, though dies having curved surfaces somewhat like fullers are frequently used. In many cases, the outline of the part that is being forged is cut into the surface of the dies so that when the heated stock is properly placed on the lower die and struck with the upper one, the stock is forced into these outlines, thus giving it the required shape. Pieces forged in this way are called *drop forgings*.

EXAMPLES OF HAMMER WORK

FORGING WROUGHT IRON

28. Welding Up Scrap.—Large wrought-iron forgings are generally made by welding up scrap, because the reworked metal shows a better grain and a closer structure than could be obtained by new metal taken directly from the puddling furnace. The scrap is sheared, or cut into pieces of the required size, and piled up on small boards, usually about 10 inches by 18 inches. These boards, with the scrap piled on them, are then placed in a heating furnace and the iron is brought to a white welding heat; this usually requires about 30 minutes in a good fire. Steel scrap cannot be welded in with wrought-iron scrap. If any high-carbon steel is placed with the wrought-iron scrap, it will be melted at the welding heat of wrought iron and will run out. Low-carbon steel, however,

will sometimes resist melting and remain in the pile; but, as a rule, it does not make a perfect weld, and hence should be avoided whenever possible. When a pile has been heated through, it is taken from the furnace with a large pair of tongs and carried to the hammer. A steam hammer, like any of those shown in Figs. 8, 9, 11, 12, 13, and 15 may be used for this work. While the scrap is heating in the furnace, a bar of iron, called a **staff,** is prepared for a handle by having one end brought to a welding heat in a separate furnace. When both the staff and the scrap are heated properly, the staff is placed on the mass of scrap on the anvil, so that the first blows of the hammer weld them together. The staff is then used for handling or moving the pile as it is forged down. The staff is cut off with a hack when the forging is completed. The forging, shown in Fig. 25, made by welding up scrap is called a **slab,** or **shingle slab,** and the operation is frequently called *shingling* or *fagoting.*

Fig. 25

A good sound iron forging can be built up of relatively small slabs; Fig. 26 shows the end, sometimes called a **crop end,** cut from a large shaft forged from iron slabs. The crop end shown was only 8 inches long, and yet the surface which was rough-turned, showed good metal almost to the end. On the back or flat side, not shown, where it was cut off, the metal was perfectly uniform, there being no visible indication of cracks between the slabs from which the piece was made.

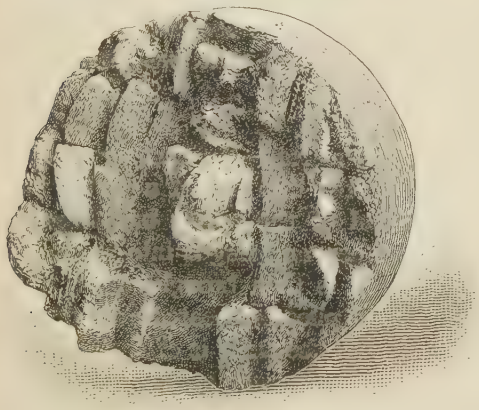

Fig. 26

29. Making Axles. For forging car axles, three or more shingle slabs containing the requisite amount of iron are piled up, placed in the furnace, and brought to a welding heat. For an axle that is to weigh about 630 pounds in the rough, two 225-pound slabs and one 180-pound slab may be taken. The lighter or thinner slab is placed between the others, because this method has been found to make a stronger axle. It takes from 30 to 40 minutes to bring such a pile to a welding heat. The three slabs are then taken out of the furnace, placed under the hammer, and a little more than half the length welded together and brought nearly to the finished size. After the pieces have been struck a few blows on the flat to weld them together, they are forged square, then octagonal, and finally round. This is termed *rough welding*, or simply *roughing*.

After one end of the piece has been rough welded, the other end is placed in the furnace, with about 1 foot of the welded end projecting to serve as a handle. After it has been heated to the welding point, it is removed, put under the hammer, and welded down, drawn out square, then octagonal, and finally round. This end is then forged to the finished size. The piece is then reversed, reheated, and the end that was first rough welded is forged to the finished size.

30. Forging Large Iron Shafts.—For forging a very large shaft, slabs are placed on the thin end of a porter bar. The slabs are piled on the end of the porter bar, brought to a welding heat, welded together, and forged into the shape of the required shaft. The end is then brought down to a shovel shape, another set of slabs piled on, heated and welded, the operation being repeated until the shaft is of the required length. As already pointed out, in forging such a shaft from iron, only sufficient working to penetrate the piece being welded and to insure a perfect weld is necessary; hence, only a sufficient number of fagots are piled up to make the forging slightly in excess of the required diameter, as this very greatly reduces the work of forging the shaft to the finished size.

When no porter bar is used for starting the shaft, it will be necessary to pile up several slabs, weld them together, flatten

out the end, and use this as a staff or porter bar for forging the shaft. The piece used as a porter bar must always be round, so that it can turn in a sling chain as the work is moved under the hammer. Shafts are usually forged under large double-frame steam hammers, as the steam hammer is seldom heavy enough for this work.

FORGING LOW-CARBON STEEL

31. Precautions in Forging Steel.—In forging steel the following important precautions should be observed: The ingot is essentially a coarse-grained steel casting, and to convert it into steel of the best quality it must undergo considerable forging, in order to produce a dense structure and bring out the best qualities. In practice, it has been found that for round work the ingot must be at least one and one-half times the diameter of the finished forging, and it is even better to have it slightly larger.

The hammer or press under which the forging is done must be sufficiently powerful to affect the ingot to its center from the very first of the work, and the effect of this complete working will be shown by the bulging of the central portion of the end of the piece being forged.

For forging, steel must be heated slowly, but without undue *soaking*, that is, it must not be heated longer than is necessary. If a cold ingot is placed in the furnace and heated rapidly, the outside may be expanded so rapidly that it will be torn from the interior. Any cracks caused by this sudden heating will form serious defects in the forging. The proper temperature for forging varies with the character of the steel, and especially with the percentage of carbon it contains. The temperature must not be near the melting point, and, on the other hand, must always be well above the point of recalescence.

32. Welding Steel.—Steel billets, blooms, or ingots should never be welded together to build up a forging, as it is practically impossible to obtain a perfect weld on large work. In building up forms of structural shapes, however, it is frequently necessary to weld pieces together, especially in ship

construction. Angles, channels, deck beams, and other structural shapes are frequently welded together when making such pieces as frames for bulkhead doors, and other similar parts of ships. This welding is usually effected by first scarfing the surfaces properly, and then heating and welding them without a flux. Such a weld will not be as strong as the unwelded portion of the piece, because the heat necessary for making the weld opens the grain of the steel to such an extent as to damage it and somewhat decrease its tensile strength.

33. Forging Press.—Owing to the structure of steel and to the fact that every blow must penetrate to the center of the forging, it is necessary that the blows should have some duration. The steam hammer produces a good surface on the forging, but the energy of the blow is not continuous enough to affect the center as thoroughly as it should. This can be remedied somewhat by driving the hammer more slowly, and following the piston with the full steam pressure clear to the end of the stroke. The steam hammer gives very good results on small- and medium-sized forgings.

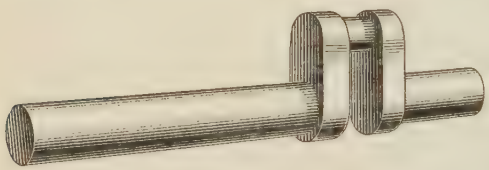

FIG. 27

The hydraulic forging press is better than a steam hammer for forging steel, because it gives a powerful squeeze instead of a sharp blow. It is used for forging very large shafts, armor plate, and similar work. Such a press, with the necessary pump and fittings, however, is very expensive, and its use would pay only where a considerable number of large pieces are to be forged. Various types of forging machines have been brought out, operated either by steam or by hydraulic pressure, which are used for squeezing steel into the desired shape.

34. Forging Crank-Shafts.—Whenever it is possible to do so, crank-shafts are forged in pairs, as the two cranks serve to balance each other when the work is turned during the

forging. An ingot, or bloom, large enough to make both pieces is used and the finished forgings are separated by cutting them apart. A crank forged in this way is shown in Fig. 27. One end of the bloom is first heated, and a triangular hack is driven, with the steam hammer, into the hot steel at *a*, Fig. 28. The hack should be made of such a height that it

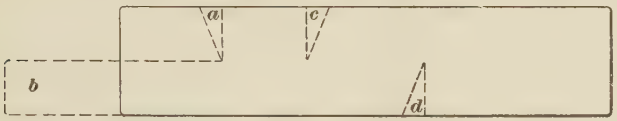

Fig. 28

can be driven its entire depth without danger of cutting deeper than is required. The end of the shaft from *a* to *b* is then drawn out under the hammer. It is first drawn square, then octagonal. The hack is next driven into the piece at *c*, and again at *d*. The part between *c* and *d* is then driven over and drawn out, first square, then octagonal, to form the part between *c* and *d*, Fig. 29. The piece is next returned to the furnace and the other end heated. It is then taken back to the hammer and the hack driven in at *e*, and the end *f* drawn down square, then octagonal, and finally round; the central portion *c d* is also rounded up. The work is again reversed, the other end heated and the portion *a b* rounded up. After the forging is cooled, it is cut off in the machine shop on the line *g h*. The inside

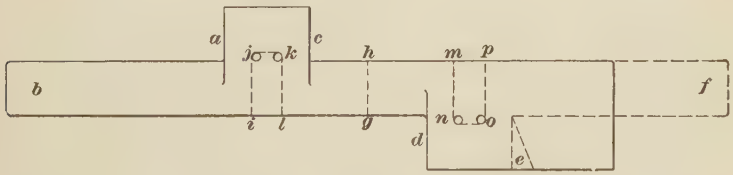

Fig. 29

portions of the cranks, at *i j k l* and *m n o p*, are not forged out, but are left in the forging as solid blocks. They are removed in the machine shop.

Where only a single crank is to be made, it is necessary to attach a balance weight to the work or to the tongs. Large steel forgings cannot be handled with the porter bar, as can

iron forgings, because it is not possible to weld the shaft to the bar. The shaft is usually gripped with a pair of tongs or clamps having a long bar or handle that takes the place of the porter bar. In some cases, a long beam of hardwood is attached to the end of the clamps, and the stocks attached to this.

35. The crank-shaft forging shown in Fig. 30 (*a*) may be made by the following modification of the method just described. This forging is to be made of a steel ingot that is cast round, and the end is therefore first drawn down rectangular as shown at *a* in view (*b*). The thickness *b* and the height *c* are the same as the thickness *d* and the height *e* of the finished forging.

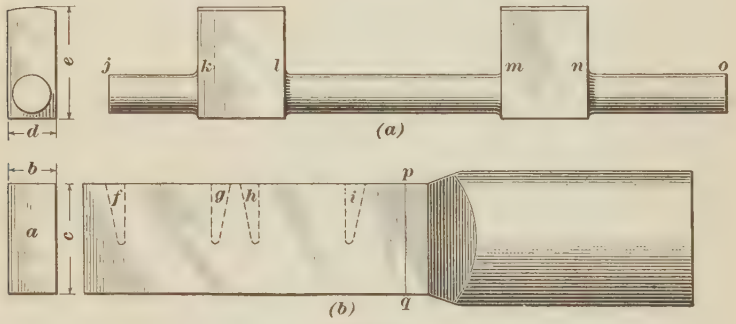

FIG. 30

A hack is driven into the forging as shown by the dotted lines at *f*, *g*, *h*, and *i*. This hack should be so proportioned that it will not cut into the shaft when driven full depth into the forging. The part of the forging at the left of cut *f* is drawn down to form the round part of the forging at *j k* and the part between the cuts *g* and *h* is drawn down to form the shaft from *l* to *m*. If the head of the hammer is too large to work in the space *g h*, swages may be used to draw down this part of the shaft. The part of the shaft from *n* to *o* is formed by drawing out the forging at the right of cut *i* and the finished forging is cut off at *p q*. When the cranks are to be set at an angle to each other, the part of the forging between *l* and *m* is heated, one of the crank blocks is gripped under the hammer and the other

is gripped by a pair of tongs to which a crane is hitched. The shaft is then twisted to the required angle. While twisting the shaft, it is bent more or less and the part from *l* to *m* must therefore be straightened after the shaft is twisted.

36. When the distance between the cranks in the finished forging is small, there is not always enough room to make the two cuts *g* and *h* so that the part of the forging between the cranks can be drawn down to the required length. The shaft may then be forged in the following manner: A finished forging of this kind is shown in Fig. 31 (*a*) and it is the same as the one in Fig. 30 (*a*) except that the distance between cranks is less

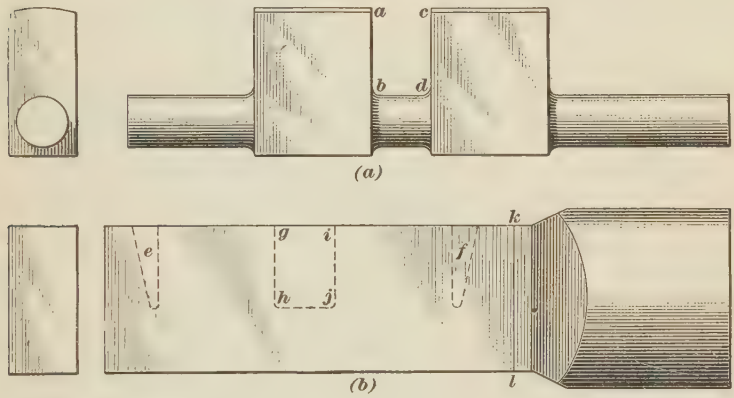

FIG. 31

than it was in the former shaft. If this shaft were to be forged by the same method as was used for the shaft in Fig. 30, the cuts forming the surfaces *a b* and *c d*, Fig. 31, would be only about $2\frac{1}{2}$ inches apart. These cuts could not be made with a hack. Hack cuts are therefore made at *e* and *f* and the ends of the shaft drawn down as in Fig. 31, but the portion *g h i j*, in (*b*), is cut out by driving a hack in along the lines *g h*, *i j*, and *h j* first from one side of the forging and then from the other. The shaft between the cranks is then rounded by the use of swages and the shaft is cut to the correct length at *k l*.

37. Forging a Connecting-Rod.—Whenever it is possible to do so, it is best to forge connecting-rods in pairs, with

their larger ends connected. This makes it possible to use one of the connecting-rods as a porter bar or handle for holding the other during the forging; also, the large ends adjoining each other can be forged at the same time under the hammer, and both ends can be forged in approximately the time it would take to forge one. Two rods joined in this way are shown in Fig. 32. After the forgings are completed they are cut apart at *a* in the machine shop. The rods from which this sketch was made were each about 14 feet long, and the large end of each rod about 12 inches by 24 inches, and the small end about 12 inches by 20 inches. The work of forging was done under a 12-ton hammer. The method of forging two pieces together and then cutting them apart is one that can be applied to advantage to a very large variety of work. It will effect a

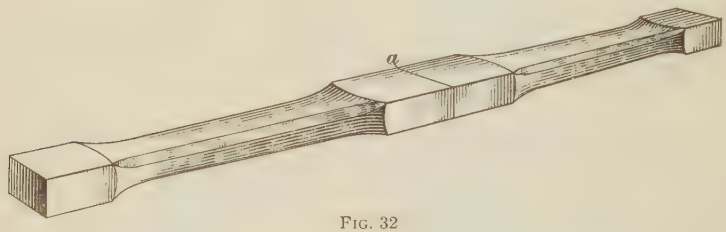

FIG. 32

saving: first, in the time necessary for heating; second, in the time necessary for forging the adjacent parts; third, by facilitating the handling of the work by balancing pieces that are heavier on one side or end than the other; and fourth, by reducing the amount of stock wasted.

38. Hollow Forging.—Hollow shafting is being used very extensively for main shafts of large engines when lightness and strength are desired. The advantages of a hollow shaft are that it is considerably stronger and stiffer than a solid shaft containing the same amount of metal. Shafts made in this manner possess another advantage, as the impurities that tend to collect at the center of the ingot, making the steel weaker and poorer, are removed and only the best part of the ingot remains in the shaft. The first hollow shafts were made by boring out the finished forging. In order to make a hollow

forging in this way, it is necessary to have a forging hammer or press that will affect the metal clear through.

39. Hollow forgings having holes less than 8 inches in diameter are usually made solid and the necessary hole bored afterwards, but when the forging is to have a hole more than 8 inches in diameter, the following method may be used: The upper, or crop, end of the ingot is cut off, thus removing many impurities and a hole large enough to take an 8-inch mandrel is then bored through the center. The ingot is then heated and placed on a mandrel under a hammer or forging press from which the anvil has been removed and replaced by **V**-shaped supports on which the mandrel rests. The mandrel supports are placed as close together as possible without interfering with the handling of the work. The upper die, which is rounded like a fuller, is placed parallel to the mandrel, so that working the ingot makes it bigger around and makes the hole bigger, but has little or no effect on the length of the ingot. As fast as the size of the hole has been sufficiently increased, the mandrel is replaced by a larger one until the required size has been reached. The work will then be larger around, but shorter than is required for the finished forging. In order to reduce the diameter of the forging and increase its length, the arrangement of the hammer is changed. A flat die is substituted for the fuller-shaped upper die, a **V**-shaped anvil block is placed under the forging, and the supports under the mandrel are removed. Starting at one end of the forging, it is worked down to a smaller diameter and drawn out in length but the size of the hole is not changed. This process of reducing the diameter and drawing the length out is repeated as many times as may be needed to reduce the forging to the required size.

The holes in hollow forgings are very irregular; as the scale cannot be removed from the space around the mandrel, and it collects and forms pockets in the forging. Holes are therefore forged somewhat smaller than the finished size, so that they can be bored out smooth. The method of making hollow forgings also leaves the outside surface rather irregular, necessitating an allowance in the outside diameter for finish.

WELDING STEEL TO IRON

40. In welding steel to wrought iron, the characteristics of both must be considered. Iron welds at a white heat, but steel must not be raised above a bright red heat. Sand is ordinarily used as a flux in welding iron, but if any flux at all is required in welding steel it must be more fusible, and hence calcined borax is very largely used. Ordinary borax will bubble when heated, due to the escape of the contained water, but if borax is placed in an iron pot and melted, the water will be expelled, and the cooled material can be powdered and used as a flux. This is called calcined borax, and sometimes borax glass.

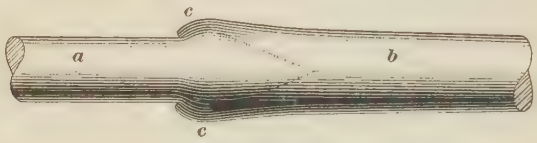

FIG. 33

In welding steel to iron, the pieces must be heated in a clean fire and the temperature raised slowly to the welding heat. A cleft weld is to be preferred, the steel being on the inside as shown at *a*, Fig. 33, and the iron on the outside. The cleft in the piece of iron *b* should be long enough so that the ends can be closed down over the outside portion of the steel piece, as shown at *c*. This serves to hold the pieces together while they are being welded. Each piece is brought to the proper heat, that is, the iron to a white heat and the steel to a bright red, the borax flux applied to the steel, and the steel driven into the cleft of the iron, after which the edges *c* are turned down and the weld completed.

FORGING HIGH-CARBON STEEL

41. In forging high-carbon steel, the following facts should be kept in mind: The purity of the steel depends very largely on the process of manufacture. The purer the steel, the easier it can be forged; the bad effects of such elements as sulphur and phosphorus are reduced to the least possible amount in the

purer steel because only very small percentages of these elements are present. High-carbon steel has a much greater strength in tension than low-carbon steel, and necessarily is much less ductile. Very large forgings are rarely, if ever, made from high-carbon steel, but in all forging operations it will be found that the high-carbon steel has a much harder structure, both when cold and when hot; more care must be taken in heating it, and a piece of given thickness will require a much heavier hammer, for good results, in forging than is the case with a softer steel.

MACHINE FORGING

FORGING MACHINES

INTRODUCTION

1. In its broadest sense, machine forging is the working of metal, either hot or cold, by means of a machine, causing it to flow in such a way as to give it some desired shape, either by slowly applied pressure or by blows. It is impossible to exclude from this machine process of working metals any forming operations on cold metals, as it has been found advantageous to forge metals at temperatures varying from ordinary atmospheric temperature to about 2,000° F. Low-carbon steel, certain brass alloys, and aluminum are frequently pressed, rolled, or punched cold. Zinc is most easily worked at a temperature of between 300° and 400° F. Aluminum can be drop-forged at a temperature slightly below a dull red heat, but it is very difficult to maintain it at exactly the required temperature. Copper can be forged hot, and pure annealed copper can be formed cold by pressing. From this it will be seen that machine forging operations are exceedingly varied in their nature.

Forging machines roll, hammer, or press the metal into the desired shape, and most forging machines may use either plain or formed dies. The use of formed dies will be considered exclusively in this Section.

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ROLLS

2. Graded Rolling.—Work of varying thickness may be done between properly shaped rolls. This is called **graded rolling,** and is really forging with revolving dies. Graded rolling is usually accomplished by passing a piece of metal lengthwise between a pair of rolls, one or both of which are more or less eccentric or have dies attached, so as to give the finished piece a tapered form or a varying thickness. Silver, German silver, and brass may be rolled by this method when cold; but iron and steel are usually rolled hot. In some cases, the stock is simply passed through the rolls; that is, the piece is placed against a guide, which serves to locate it properly before starting through the rolls; the rolls then grip it and carry it from the operator, requiring no further attention from him. In other cases, dies are fastened to the rolls. These dies do not extend all around the rolls, and when the parts not covered by the dies are next to each other, an open space is left between the rolls. The rolls turn continuously, and when the open space appears the work is passed through it. As the rolls turn, the dies come together, grip the work, and roll it toward the operator. The advantage of using a machine in which the work is done by rolling the material toward the operator is that where several passes are required all work can be done by one man, while with rolls carrying the work away from the operator it is necessary to have a man at the back of the machine to return the partly finished pieces. Graded rolling is sometimes done to break down stock or to rough it to shape, so that it may be finished by drop forging.

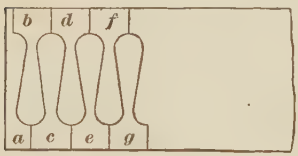

FIG. 1

3. Some of the operations in the making of spoons are excellent examples of graded rolling with dies. The blanks are punched from a sheet $\frac{1}{4}$ inch thick, in the form shown in Fig. 1; the piece *a* is waste, and *b*, *c*, *d*, *e*, *f*, and *g* are spoon blanks. The large end of the spoon blank, which is to form the bowl,

is first made wider by cross-rolling; this is done in some cases by passing the blank sidewise between rolls about 6 or 8 inches in diameter, the rolls being located between housings, as shown in Fig. 2. A part of each roll is made smaller in diameter, that is, it is cut away so as to clear the spoon handle, shown at *b*. The portions *r r* of the rolls do the cross-rolling; the rolls are connected by suitable gears, which are placed on the ends of the roll shafts. In other cases, the cross-rolling is done between overhanging rolls, as shown in Fig. 3; these rolls are 10 or 12 inches in diameter, to insure the necessary stiffness. The portions of the rolls between the housings are frequently used for other work. Driving gears are located on the ends of the roll shafts at the side *g*.

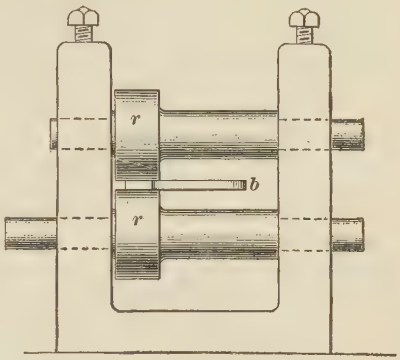

FIG. 2

The thickness of the metal varies in different parts of a spoon and this varying thickness is produced by graded rolling. Part of the circumference of the rolls is cut away so that the length of the circumference remaining is equal to the length of the spoon. The part of the roll that is not cut away is shaped so as to produce the desired taper on the work. A different set of rolls must therefore be made for every size or style of spoon. In some cases the work passes through the rolls away from the operator and falls out on the other side, while in others it is rolled toward the operator.

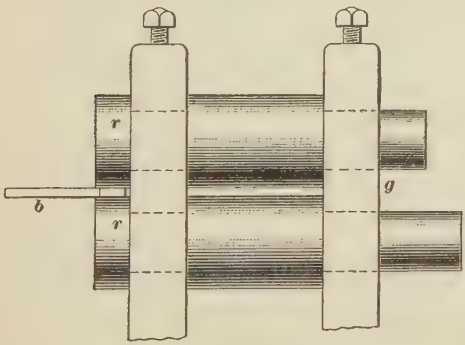

FIG. 3

4. In rolling rifle barrels, steel billets are heated in a furnace and then passed through successive grooves in a pair of special eccentric or graded rolls, until the barrel is reduced to the proper size and has the required taper. As the billet passes through the first groove, it is seized by a helper at the back and passed over to the workman in front. The work passes between the rolls with the large end first, passing once through each groove, except the last, through which it is passed twice; the work is given a quarter turn between each two passes. As

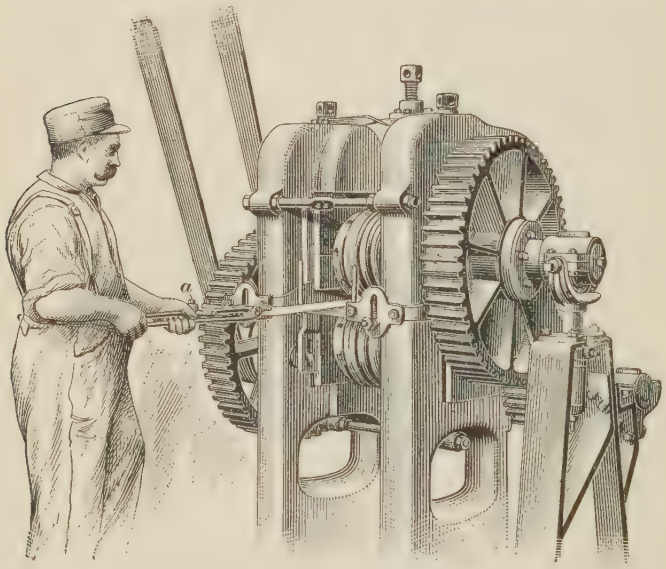

FIG. 4

soon as the barrel is rolled to size, the ends are sawed off to the proper length.

5. A pair of graded rolls fitted with dies for special forging work, on either hot or cold metal, is shown in Fig. 4. These rolls are provided with nuts and collars, between which the rolling dies are clamped. The dies can be removed and changed at will, so that a large variety of work can be done on one pair of rolls. The rolls turn so that the work is run toward the operator, and, as the dies do not extend over the entire

circumference of the rolls, the metal is passed between them at the time in the revolution when the dies are out of the way. The work is located by guides, which control its position both vertically and horizontally. When rolling hot metals, the location is determined by a stop *a* on the tongs, Figs. 4 and 5.

Fig. 5

It will be noticed that this is simply a clamp screwed to the tongs; it is brought against a guide fastened to the front of the rolls, to show how far the iron should be pushed in between the rolls. Sometimes the end of the tongs strikes the guide, and this serves to locate the work. After the work has been placed in position, the revolving dies catch the piece and roll it toward the operator. As soon as the dies leave the piece, the operator puts it in position for a second pass through the rolls, either giving it a quarter turn and returning it through the same groove, or giving it a quarter turn and placing it in the next groove; in this way the work is continued until completed. In the machine shown in the illustration, there are three grooves, and the work is given two passes in the first groove, two in the second, and three in the third groove.

6. In Fig. 6 is illustrated the back of the machine shown in Fig. 4. In this view, the dies *a* are clamped between the nuts *b* and the collars *c* on the other ends of the rolls. The work *d* is shown in position ready for the dies to grip it as they come around to the proper point; the arrows show the direction in which the rolls are turning. A peculiar arrangement of gearing is used for driving these rolls, which admits of the adjustment of the distances between the rolls; this is accomplished by driving the top roll by a train of three gears, one being an idler swinging about one of the others and meshing with both.

7. Screw-Thread Rolling.—Screw threads are rolled on wood screws, track bolts, machine screws, and many other

screws and bolts, from small sizes up to $1\frac{1}{2}$ inches in diameter. The thread is formed by rolling the stock between suitable dies, with sufficient pressure to force the material out of the grooves to form the thread points. That is, the cold metal is caused, by the pressure on the dies, to flow from the bottom of the spaces and form the full thread. It is in reality a cold-forging process.

8. Machines for rolling screw threads are made both horizontal and vertical, but since the horizontal and vertical machines are alike in principle only one will be described here.

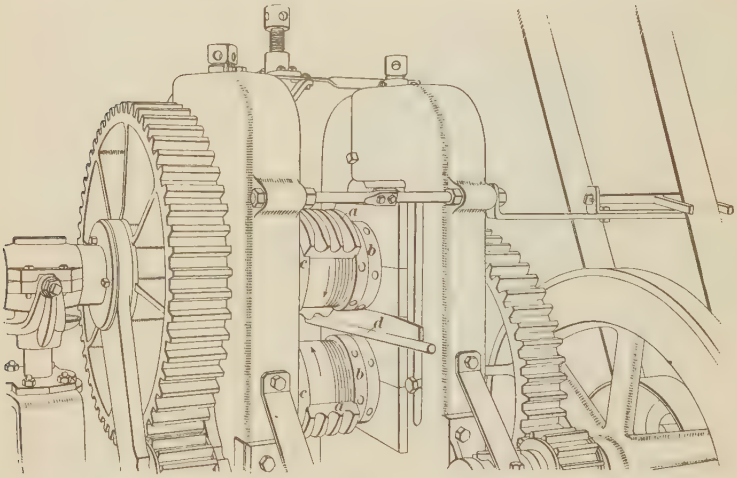

FIG. 6

The front view of a vertical thread-rolling machine is given in Fig. 7. There are two dies *a* and *b*; *a* is fastened to the frame of the machine, and *b* is attached to a crosshead partly shown at *c*. The blank that is to be threaded is placed on the feed bar *d* and is introduced between the dies at the proper moment by the pusher, or starter, *e*. To start the blank, the feed bar *d* is automatically withdrawn from between the dies and the starter moves forward, pushing the blank between the dies. Both the feed bar and the starter are moved by the cam *f* on the driving shaft. The crosshead *c* is moved through the connecting-rod *g*

and yoke h by a crank on the shaft i. The shaft i is driven from the pulley j by gearing of which k is part. The yoke h is arranged so that, when the gear k turns in the direction of the arrow, the crosshead is given a slow motion on the down, or working, stroke and a quick motion on the up, or idle, stroke. The back of the crosshead c bears on a set of rollers,

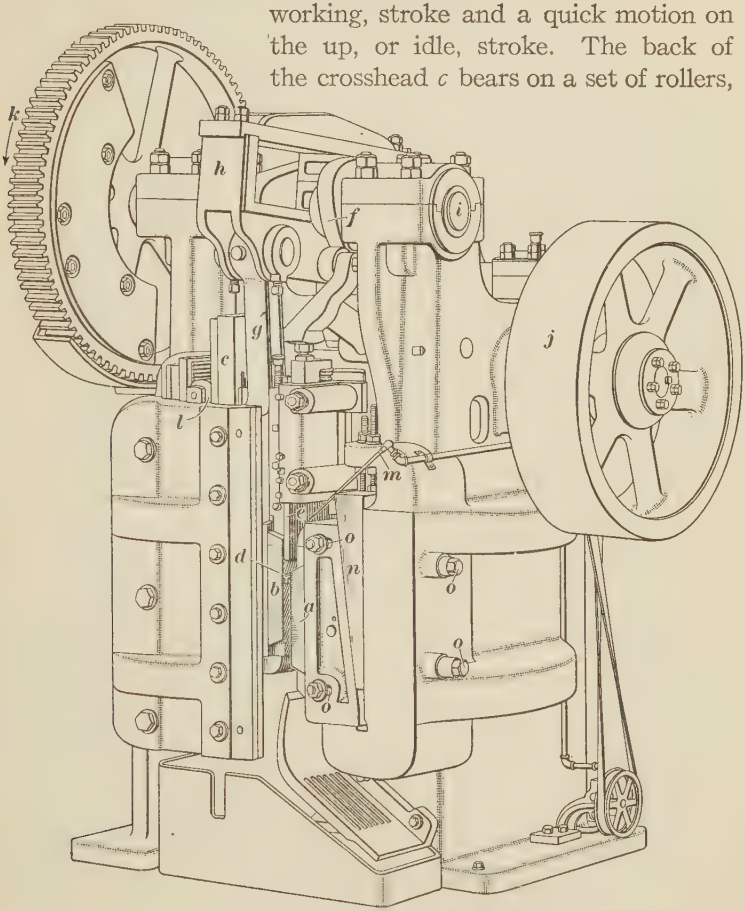

Fig. 7

one of which is shown at l, and the working faces of the dies are lubricated by oil that flows from the pipe m. The stationary die a is adjusted to roll a full thread by the wedge n and is clamped in the final position by the bolts o.

9. The threads on the dies are laid off at an angle as shown in Fig. 8, which is a die for forming a right-hand thread. The length of the die is about three or four times the circumference of the blank so that the screw will turn around, between the dies, about that number of times in forming the thread.

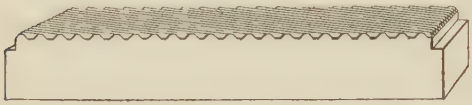

Fig. 8

Screw threads are rolled on many small pieces, the material being either hot or cold, depending on the size and character of the article. The rolled thread is claimed to be much stronger than a cut thread, but it is exceedingly difficult to keep dies in shape for rolling threads on hot stock; hence, this process is used mostly for rolling threads cold

Fig. 9 shows how the metal is displaced by the dies to form the thread on the bolt *a*; the dotted line *b c* shows how deep the dies press into the stock, and also how the diameter is increased on account of the thread. As the finished thread must have a definite diameter, it is very important that the stock used should be of the right size; if the stock is large the screw will be too large, and if too small the screw will either be too small or the threads will not be perfect. The size of stock required to make a rolled thread of any given diameter can be calculated, but owing to the fact that the rule is long and rather complicated, and that the diameter of stock must sometimes be changed after trial because the metal will not always flow readily into the points of the threads, a simpler but less exact rule is ordinarily used. The first trial size of stock is obtained by subtracting the depth of the thread from its outside diameter. The depth of the United States standard threads may be found by dividing .6495 by the number of threads per inch; and the depth of V threads

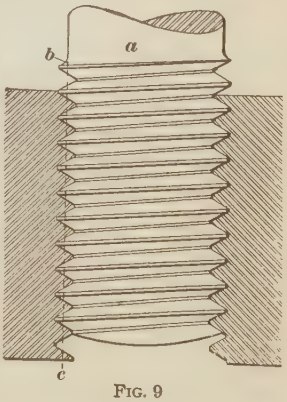

Fig. 9

may be found by dividing .866 by the number of threads per inch. The diameter of stock for some of the most common sizes of rolled threads is given directly in Table I.

TABLE I

SIZE OF STOCK FOR ROLLED THREADS

Diameter of Screw	United States Standard Thread			V Thread		
	Number per Inch	Depth Inch	Diameter of Stock Inches	Number per Inch	Depth Inch	Diameter of Stock Inches
$\frac{1}{4}$	20	.033	.217	20	.043	.207
$\frac{3}{8}$	16	.040	.334	16	.054	.321
$\frac{1}{2}$	13	.050	.450	12	.072	.428
$\frac{5}{8}$	11	.059	.566	11	.079	.546
$\frac{3}{4}$	10	.065	.685	10	.087	.663
$\frac{7}{8}$	9	.072	.803	9	.096	.779
1	8	.081	.919	8	.108	.892
$1\frac{1}{8}$	7	.093	1.032	7	.124	1.001
$1\frac{1}{4}$	7	.093	1.157	7	.124	1.126
$1\frac{3}{8}$	6	.108	1.267	6	.144	1.231
$1\frac{1}{2}$	6	.108	1.392	6	.144	1.356

10. To illustrate the use of the table, suppose a $\frac{1}{2}$-inch United States standard thread is to be rolled. How many threads per inch and what size of stock should be used? Find $\frac{1}{2}$ inch in the left-hand column; and, following horizontally across the table, in the columns headed United States Standard Thread, it is found that there are 13 threads per inch, and the depth of the thread is .05 inch, and the stock should be about .45 inch in diameter. Again, suppose a $\frac{7}{8}$-inch V thread is to be rolled. How many threads per inch and what size of stock should be used? Find $\frac{7}{8}$ inch in the left-hand column of Table I and, following horizontally across the table to the columns headed V Thread, the number of threads per inch is found to be 9, and the stock should be about .779 inch in diameter.

An example may be used to explain the determination of the size of stock when it is not obtainable from Table I.

EXAMPLE 1.—What size of stock should be used to make 12 rolled United States standard threads per inch, $\frac{3}{4}$ inch in diameter?

SOLUTION.—Owing to the fact that a $\frac{3}{4}$-inch screw does not ordinarily have 12 United States standard threads per inch, this combination does not appear in Table I. It will therefore be necessary to calculate the size of stock required to make these threads. According to the explanation just given, the depth of the thread is

$$.6495 \div 12 = .054 \text{ in.}$$

and the diameter of the stock is

$$.75 - .054 = .696 \text{ in.} \quad \text{Ans.}$$

It is sometimes required to find the diameter of thread that will be produced by rolling a given number of threads per inch on stock of a given size. In this case the depth of the thread should be added to the diameter of the stock, the depth of the thread being found as described in the foregoing example.

EXAMPLE 2.—What outside diameter of thread will be produced by rolling 10 V threads per inch on $\frac{3}{4}$ inch stock?

SOLUTION.—The depth of the V thread is

$$.866 \div 10 = .0866 \text{ in.}$$

and the outside diameter of the thread is

$$.75 + .0866 = .8366$$

which is practically .837 in. Ans.

11. Bending Rolls.—Plates are bent in bending rolls, which are placed as shown at *a*, *b*, and *c*, Fig. 10. Roll *a* is arranged so that it can be moved toward or away from *b* and *c*, in order to give the plate *d*, that is being rolled, the desired curvature. The roll *a* is called the *bending roll* and rolls *b* and *c* are the *pinching rolls*. The side view of a set of bending rolls is shown in Fig. 11, in which the rolls *a* are driven by electric motors *c*, through gears *b*, *d*, *e*, *g*, *f*, and shaft *h*. A gear *f* is

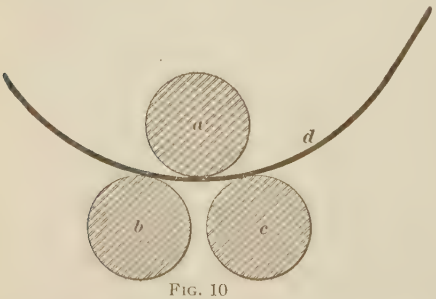

FIG. 10

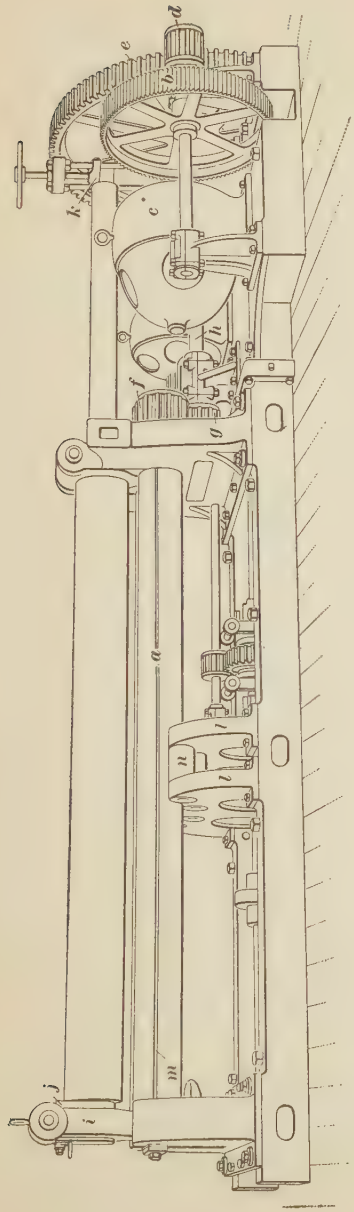

FIG. 11

attached to each of the pinching rolls, both of which are driven by gear *g*. The farther motor also drives gear *e* through gearing that is not shown, similar to *b* and *d*. The pinching rolls, which are driven, are also called *live rolls;* and the bending roll, which is not driven, is called a *dead*, or *idle*, *roll*.

12. The pinching rolls are stiffened by supports *l* and rollers *n* so they will not spring down in the middle. Each pinching roll has three slots *m* to help start the plates squarely through the rolls. The plate is put between the bending roll and one of the pinching rolls; then, as the roll rotates, the edge of the plate is caught by one of the slots, bent up around the bending roll and started between it and the other pinching roll. Cylindrical work is removed from the rolls by turning down the end *i* with the bearing *j*, it being hinged for that purpose, and raising the roll by the rigging shown at *k*. The curvature of the plate may be controlled by raising or lowering the pinching roll. This is done by a mechanism partly shown at the right of the supports *l*. The two ends of the bending

roll may be moved together, or either end may be moved independently of the other end. By moving one end of the bending roll closer to the pinching rolls than the other, conical work may be formed.

HAMMERS

13. Steam Drop Hammer.—The steam drop hammer has many of the advantages of other drop hammers and it possesses one advantage not shared by them; that is, that steam may be used for driving the piston down more rapidly,

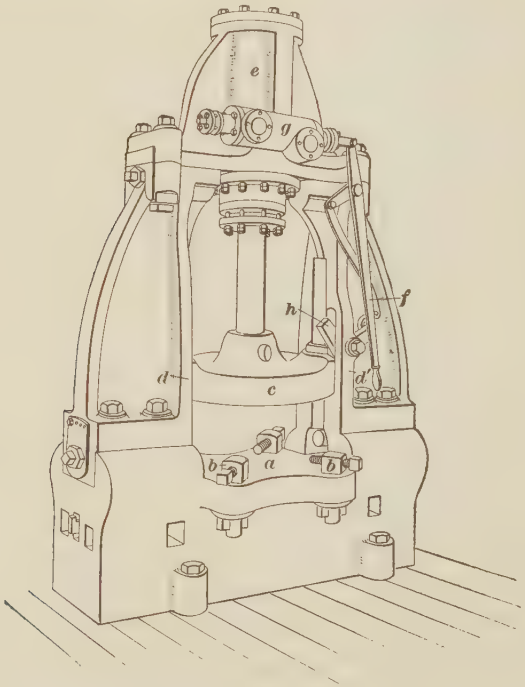

FIG. 12

and hence an exceedingly quick and powerful blow can be struck; or the piston may be let down slowly until the upper die rests on the work, when the steam pressure is applied and the dies forced together with a uniform pressure, as in the case

of an ordinary power press. The work may then be finished by one or two blows of the hammer; in other words, the steam drop hammer is capable of a wider range of work than other forms, but as a rule it requires a somewhat higher degree of skill in the operator.

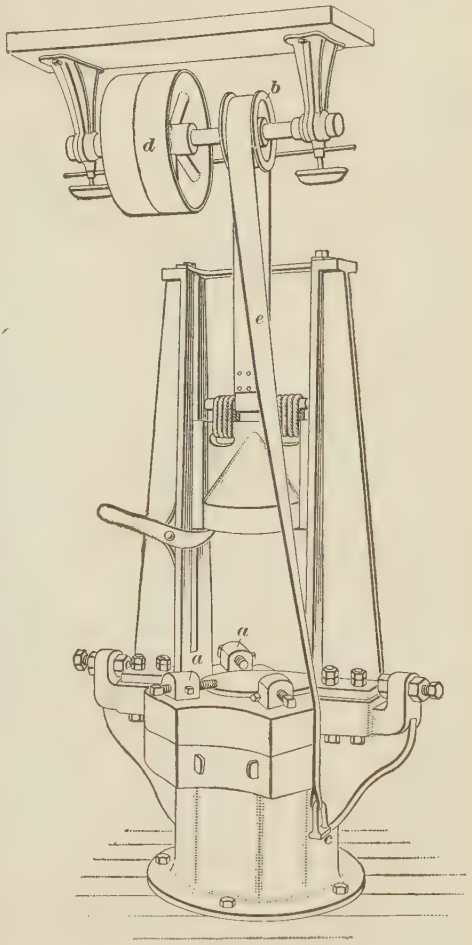

Fig. 13

14. Steam Drop Press. — There is a large variety of work that must be pressed to bring it approximately to shape, and then a few sharp blows from a hammer must be struck to finish it. The steam drop press, which closely resembles the steam drop hammer, has been brought out to meet this demand. One form of drop press is shown in Fig. 12. The lower die is held in place on the base *a* by the poppets *b*, which extend through the base and are secured by keys below. The head *c* that carries the upper die, and moves between the guides *d*, *d'*, may be allowed to fall by gravity or may be forced down by steam or air pressure acting on a piston in the cylinder *e*. The lever *f* operates the piston valve in the valve chest *g*, and also moves the latch *h* out of the way when starting the head

from its highest position, where it is held by the latch when the press is not running. This type of press is used for large thin work, such as dish pans, where the work is first pressed into shape and then finished by two or three quick blows.

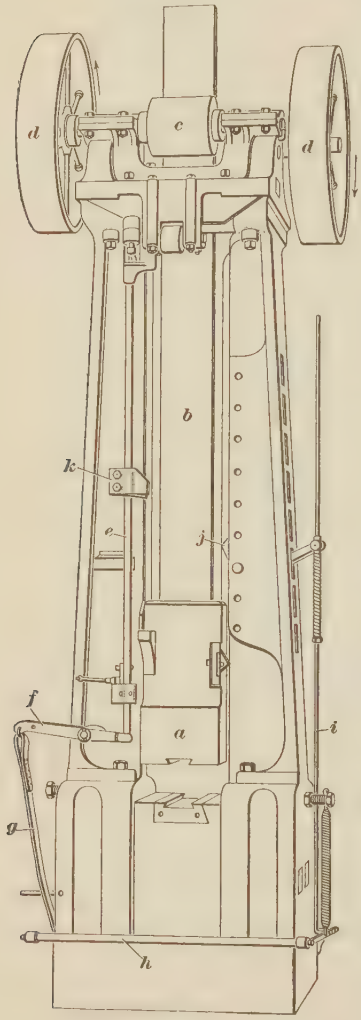

Fig. 14

15. Strap and Pulley Drop Press.—In the strap and pulley drop hammer, shown in Fig. 13, the weight is lifted by pulling on a strap that passes over a constantly rotating pulley. The pulley *b* is kept rotating by a belt on the pulley *d*, and when the end of the strap *e* is hanging loose the friction on the pulley is not sufficient to lift the weight. When the operator brings pressure on the strap, either by pushing his foot down in the stirrup at *c* or by gripping the strap higher up with his hand and pulling down, the friction of the strap on the pulley *b* is increased to such an extent that the hammer head is lifted. When the head reaches the desired elevation, the tension on the strap is relieved, allowing it to slip over the face of the pulley as the head falls.

The **poppets,** shown at *a*, are used to hold the lower die in place. They are made with long shanks that fit holes in the base of the hammer, and with adjusting screws through the tops to locate and hold the die.

16. Board Drop Hammer.—One of the most common forms of drop hammer is known as the board drop hammer, one form of which is illustrated in Fig. 14. The hammer head *a* and board *b*, to which it is attached, rise and fall together. Friction rolls *c* on each side of the board are attached to shafts carrying pulleys *d* turning in opposite directions, and run by belts in the directions shown by the arrows. The friction rolls are thus run continuously in the directions required to raise the board, but in their normal position they just clear the board. The rod *e* operates a cam that moves the rollers *c* so that they grip the board and raise it and the hammer. The foot treadle *h* is connected by a strap *g* to the lever *f*, and is also attached to the rod *i*, and thus operates the latch *j*.

17. When not in use, the hammer head is usually held up by the latch *j*, which is placed at about the highest point from which it is desired to have the hammer drop. When it is desired to strike a blow, the treadle is depressed, which pulls out the latch *j*, and permits the outer end of the lever *f* to rise and the rod *e* to fall. When the hammer falls, the lug on the hammer head strikes the lower dog on the rod *e*, carrying the rod down and forcing the friction rolls *c* against the board. The hammer is then raised, the rolls remaining in contact until the hammer head strikes the upper dog *k* on the rod *e*, thus raising the rod and throwing the friction rolls out of contact with the board. The hammer then again falls, striking another blow, and carrying down the rod *e* and throwing the rolls into contact as before. This process is repeated automatically, striking continuously, until the treadle is released, and raised by the spring shown at the right-hand side of the hammer; then the latch *j* again catches the hammer head and holds it in the raised position. Light blows may be struck by releasing the treadle at each rise of the hammer before the hammer head strikes the dog *k*, throwing out the friction rolls and causing the hammer to drop before it has reached its full height. The operator can thus vary the stroke as conditions may require. The hammer may be set for different heights of drop by moving the latch *j* and the dog *k* up or down.

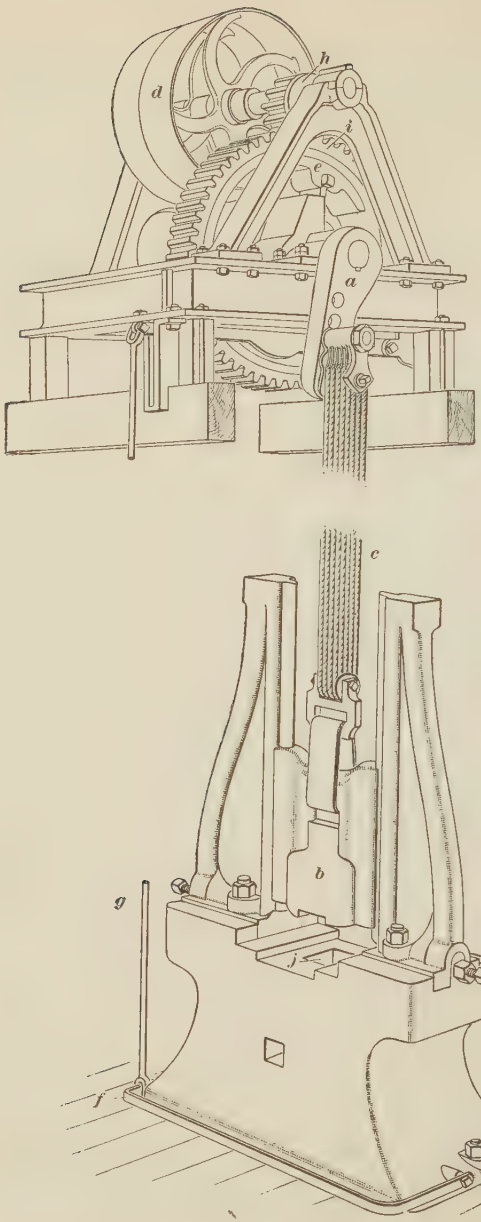

Fig. 15

18. Crank Drop Hammer.—A common form of crank drop hammer is shown in Fig. 15. In this type of hammer, the lifting mechanism is arranged in such a manner as to rotate the crank *a*, thus lifting the hammer head *b* by means of the ropes *c*, or by a leather strap. The mechanism is driven by a belt on the pulley *d*, on the shaft carrying the pinion *h* that drives the gear *i*. A clutch *e* is so constructed as to raise the hammer after each stroke and hold it in its highest position until the treadle *f* is depressed. The treadle *f* is connected, through the rod *g*, to the clutch *e*. By keeping the treadle depressed, the hammer will strike successive blows.

19. Advantages of Board and Crank Drop Hammers. Board and crank drop hammers have a number of points that distinguish them from each other. In general, a board drop hammer strikes a quicker or sharper blow for the same weight of hammer head and same height of drop. The blow of the board drop hammer may also be quickly regulated by varying the height of the drop.

The *crank-lift*, *rope-lift*, or *strap-lift* drop hammer, as it is variously known, is largely used for bending, shaping, straightening, and welding. These hammers are used extensively by the manufacturers of agricultural implements, and also by malleable-iron companies. The crank machines have an advantage in the lifting arrangement because the board drop hammer depends on friction for lifting the hammer, while with the crank drop hammer, the lifting is positive. The board and gearing are expensive, so that a crank machine of a given capacity and weight of drop will cost less than a board-operated machine. The form of the lifting device is not of much importance in the case of light work, but for manufacturing where large forming dies are used it is a point well worth considering. As a rule, the crank machine is simpler and requires less skill for its operation; hence, it is preferred for rough work. It is also used very extensively for forging soft metals cold, as in making spoons, watch cases, and similar work.

In many classes of work, it is absolutely necessary that the hammer head or drop should fall from two or more heights, in

order to strike light or heavy blows when forging; and sometimes, as the work is turned from side to side, these light and heavy blows must alternate. For such work the crank hammer is not suitable, and it is necessary to use a board drop hammer. Even for the lighter class of forgings, especially where the dies are frequently changed, the board drop hammer is generally considered the better.

20. Die Forgings.—Die forgings are produced in formed dies that are shaped more or less closely to the outline of the forging. Various machines, such as drop hammers, steam hammers, and presses, are used to force the stock into the dies. A *drop forging* is a die forging that is produced by using the force of a falling weight to drive the stock into the dies. Drop forgings may be produced on a drop hammer or a steam hammer. When a steam hammer is used, the force of the blow struck by the falling hammer head may be increased by steam pressure behind the piston. The general process of making die forgings will be explained by means of a simple example requiring but two operations and other forgings requiring these and additional operations will be described later throughout the remainder of this Section.

21. The clips used to hold the wooden and iron parts of a wagon axle together are made flat, as shown in Fig. 16, and are bent to fit the axle on which they are to be used. The ends *a* and *b* are threaded to receive nuts that hold a yoke on the clip after it has been bent. The flat part is made very thin, sometimes only $\frac{1}{32}$ inch thick, so that it can be bent cold. Recesses in the forging dies form the round ends *a* and *b*, and the conical parts *d* and *e* that join them to the flat part. The forging dies are shown in Fig. 17, in which (*a*) is a view of the face of the upper die, (*b*) is a section of the upper and lower dies, showing the recess in which the forging is made, and (*c*) is the face of the lower die. The top surface of the lower die in

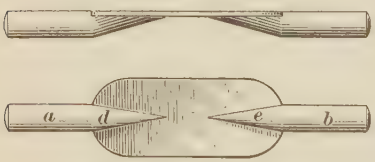

FIG. 16

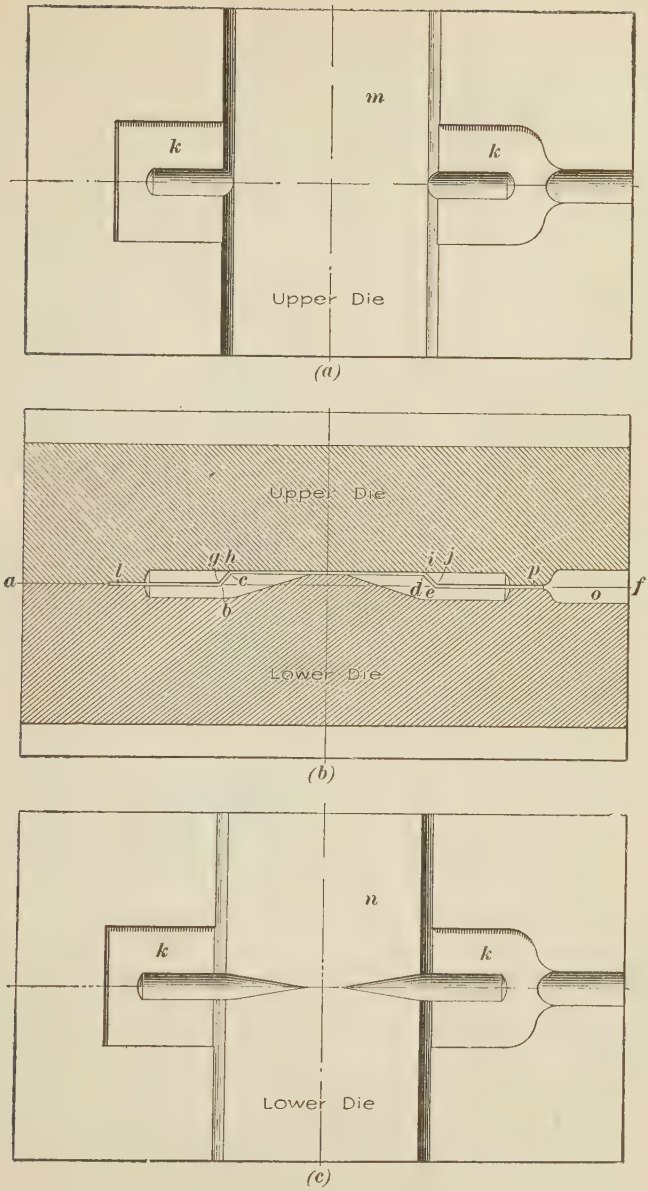
m
k
k
Upper Die
(a)
Upper Die
a
l
g h
c
b
i j
d e
p
o
f
Lower Die
(b)
n
k
k
Lower Die
(c)

FIG. 17

view (*b*) is on the line *a b c d e f* and the lower surface of the upper die is at *a g h i j f*. From *h* to *i* the upper die does not touch the lower die, and the distance between the dies, when the upper die is clear down, gives the thickness of the flat part in Fig. 16.

22. This forging is made from bar iron, which must be large enough to fill the die at the largest part. There are other parts of the die that such a bar more than fills and there must therefore be some provision made for the disposal of the excess metal where it can later be removed without injury to the forging. This provision is made by leaving a shallow recess *k* in Fig. 17 (*a*) and (*c*), called the flash, which makes a narrow opening *l*, in (*b*), around the forging impression. The excess metal squeezed out into the flash around the forging is called the *fin* and sometimes, also, the *flash*. Since these dies do not come together between *h* and *i*, that is, the surfaces *m* and *n* do not come together, the flat part of the forging can spread out as much as necessary and no flash need be provided for this part of the forging. The part of the bar that is not needed for the forging, sticks out of the die through the *sprue o*. The sprue is connected with the die impression by the *gate p*.

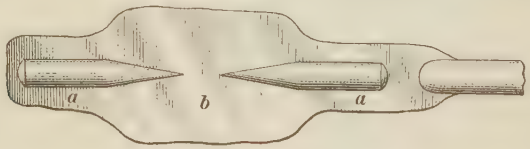

FIG. 18

23. The forging produced by the forging dies is shown in Fig. 18 with the fin *a* still attached and the flat part *b* is very much larger than is required in the finished forging. The fin *a* is removed by a punch and die, shown in Fig. 19 (*a*) and (*b*), which also trim the flat part *b* to the required size and shape.

The die, or *trimmer*, shown in (*b*), is made of two blocks *a* and *b* in which an opening *c* has been cut. This opening is the size and shape of the outline of the finished forging and it extends clear through the trimmer. The punch *d* in view (*a*) fits in the opening *c* in the trimmer, and its lower surface is

shaped to bear evenly on all parts of the forging. The rough forging shown in Fig. 18 is laid on the trimmer, Fig. 19 (*b*), so that the round ends rest in the parts *e* and *f* of the opening and the fin extends out over the surface of the trimmer. The punch is then brought down on top of the forging, forcing it through the trimmer, cutting the fin off and leaving it on the surface of the trimmer. The fin must be cut from the end of the bar from which the forging was made, so that it will not interfere with the making of the next forging. The *cut-off g*

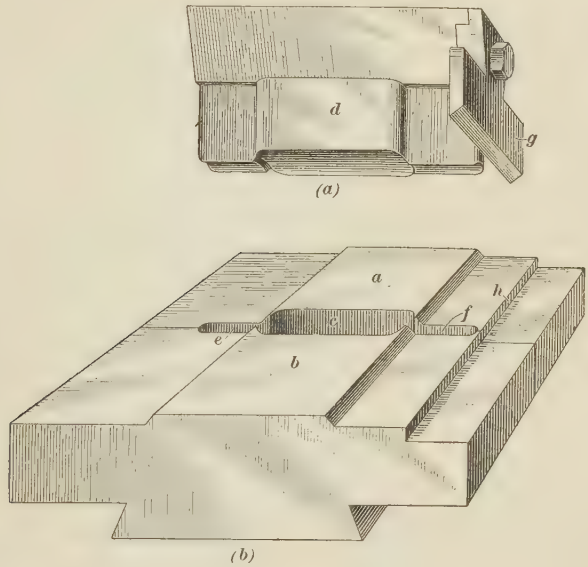

Fig. 19

is therefore fastened to the end of the punch so that it comes into action over the shoulder *h* when the punch has nearly severed the forging from the fin. The cut-off must be wide enough to reach clear across the fin and cut it entirely off. The trimmer is made of two blocks, so that the opening *c*, when it has been enlarged by wear, can be brought back to the required size and shape. The shape of the opening in each block is first trued up and the joints between the two blocks are then faced off to make the opening of the right size.

24. It is not always possible to complete a forging in one die, as was done in the case just described, and the forging dies are then provided with two or more impressions, thus doing the required work on the stock in a series of steps. The number of blows that must be struck depends on a number of conditions, but must always be enough to make the upper die strike the lower die. The number of blows will be affected by such conditions as the weight of the hammer, the height of the drop, the size of the stock, the kind, quality, and temperature of the metal, and the depth and shape of the recesses in the dies. In general, the heavier the hammer, the higher the drop, the smaller, hotter, and softer the stock, and the shallower the recesses in the dies, the fewer will be the number of blows required to finish the forging.

25. Such articles as spades, shovels, scoops, conveyor buckets, and wheelbarrow bodies may be formed in dies by drop hammers. The lower die forms the outside and the upper die the inside of the article. Some of these articles, such as wheelbarrow bodies, are made in steam drop hammers. The upper die is brought down against the stock, and steam is then turned on, pressing the stock into the lower die, and a few light blows are then struck to remove wrinkles and make the stock fit the die closely. Shovels are made under drop hammers. The heated stock is placed over the lower die and struck as many blows as are needed to make it fit the die closely. The dies with which scoop shovels are formed are shown in Fig. 20. The lower die, shown in (*a*), forms the outside of the shovel and the inside is formed by the upper die, shown in (*b*). The back of each die block is planed smooth, so as to give a good bearing on the bed or the head of the hammer. The lower die is held in place by setscrews passing through poppets on the bed of the hammer. The upper die is fastened to the hammer head by bolts that pass through ears on the head, or by a dovetail

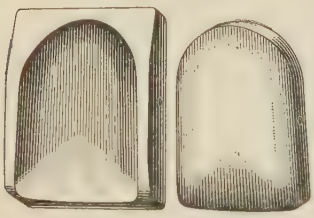

FIG. 20

and key. Suitable stops are provided to facilitate placing the upper die properly over the lower one.

26. Automobile front axles are frequently drop-forged, the dies usually being long enough to forge half the length of the

FIG. 21

axle at a time. The order in which the operations are performed and the details of some of the operations depend largely on the design of the axle and the size of stock of which the axle is being made. A front axle that is forged from square bar is illustrated in Fig. 21. The bar is large enough to make the body of the axle, but upsetting at *a* and *b*, as shown in Fig. 22, is necessary, to make the forked end *a* and the spring pad *b*. This operation is performed before the axle is taken to the forging hammer, in an upsetting machine, which will be described later. The forging is done in two stages; the first is a roughing operation which spreads the end preparatory to forming the forked end. A steam hammer is shown in Fig. 23 fitted with the roughing dies for this axle. The upper die *a* is keyed to the hammer head with a key *b* that is formed to fit the space between the dovetail on the die and the side of the slot in the hammer head. The lower die *c* is keyed to the anvil. Two keys are used in this case, one driven from each end of the die. When making the dies, one end and one side of the

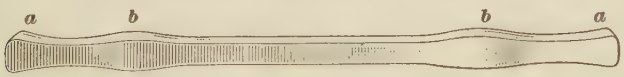

FIG. 22

die block are first planed straight and square with the working face of the die and with each other. The impressions in the dies are then laid out so that they will come together when these squared edges are in line with each other. The squared ends are lined by moving one or the other die backward or

forward as may be required. The sides are lined by moving the hammer frame sidewise on the anvil block. This moves the upper die crosswise, but does not change the position of the lower die. When the dies are properly lined, the hammer frame is fastened down by anchor bolts *d*. Heavy springs are placed under the nuts on the anchor bolts so that when such a heavy blow is struck that there is danger of breaking the hammer, the hammer is lifted slightly from the anvil block.

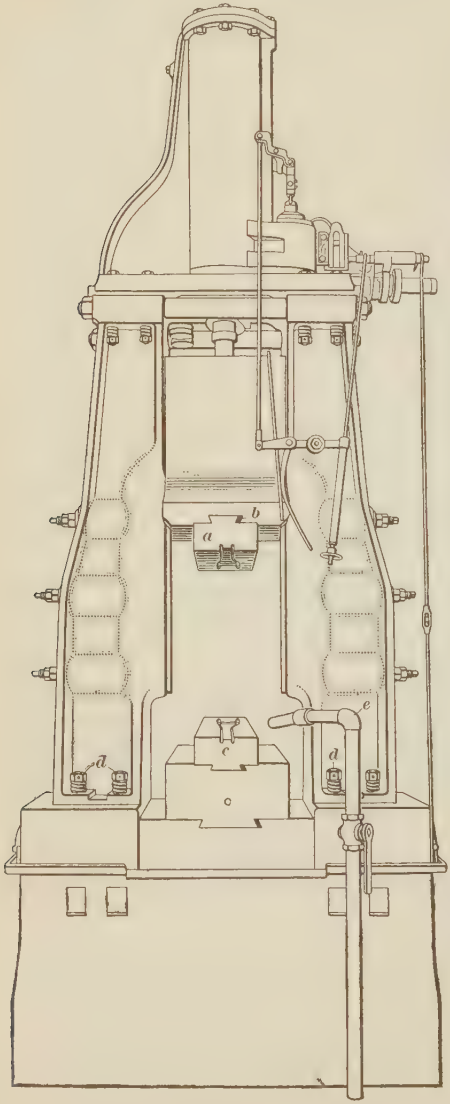

FIG. 23

27. Considerable scale forms on the material that is heated for forging, and some of it when loosened by the forging operation drops into the lower die. If the scale were allowed to stay in the die, the forging would be rough and not true to the die. A blast of air from the blast pipe *e* is therefore directed on the lower die to keep it free from scale. The dies are long enough to forge slightly more than half the length

of the axle, so one end of the axle is heated and forged and then allowed to cool. The other end is then heated and forged in the same way. In order to facilitate the forging operation, the finishing dies are set up on a hammer beside the first one so

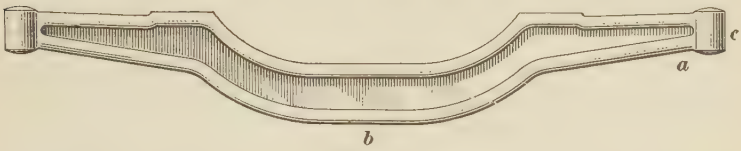

Fig. 24

that, when one end has been rough forged, it is taken to the finishing hammer and finished with the one heat, and the fin is trimmed in a trimming press. In this way each end is completely forged and trimmed with one heat. The axle is forged straight, and is bent to the required form on a press.

28. A large axle of somewhat different design from the one shown in Fig. 21 is illustrated in Fig. 24. This axle is heavier at the middle than at the ends and it is therefore not possible to use stock large enough to fill this part of the die without leaving an excessively large fin at other parts of the forging. Stock that is larger than is required by the part of the forging at *a*, but not quite large enough for that at *b* or at *c*, is therefore used. The forging of each half of this axle is completed in four operations with two dies. The operations are fulling, breaking down, roughing, and finishing. The first three operations are performed under a roughing die and the fourth operation under a finishing die.

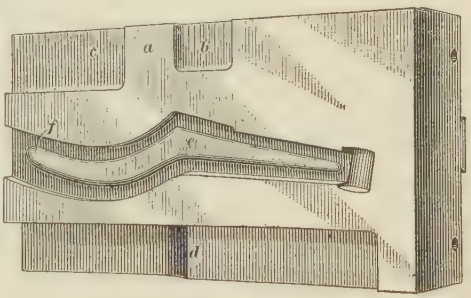

Fig. 25

29. The lower roughing die is illustrated in Fig. 25. The fuller, shown at *a*, throws the metal both ways, into the spaces *b* and *c*. The metal in *b* provides stock for the formation of the

axle end, and that in *c* provides stock for the heavier portion of the axle body. The stock is then bent in the breakdown *d* so that it will lie over the roughing impression. The upper roughing die is like the one shown, excepting that the breakdown projects from the face of the die block instead of being cut into it. After the stock is bent, it is roughed out in the impression *e*. The projection in the center of this die gradually tapers out at *f* so as to throw the surplus metal toward the middle of the axle where it will be needed in the finishing operation. The finishing impression is shown in Fig. 26. The other die of this pair is like the one shown. The impression brings the forging to size and a flash *a* is provided to take the excess metal that is squeezed out. These dies, like those for the other axle, forge half the axle at a time. Such dies as these are rather heavy and must therefore be lifted by a crane. In order to facilitate the lifting of the dies, holes *b* are drilled in the ends of the die block, and steel pins, over which the crane chain is fastened, are stuck into these holes.

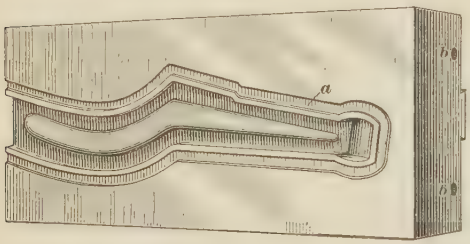

FIG. 26

30. Drop-Hammer Foundations.—As it takes some appreciable time for the blow to penetrate to the center of a piece of metal, drop hammers are sometimes provided with an *elastic foundation*. The elasticity has the effect of distributing the force of the blow over a longer period of time, thus causing it to penetrate deeper. Such a foundation is usually made of large timbers, carefully squared and made to fit each other quite accurately, as shown in Fig. 27. The anvil *a* is then placed on the foundation, usually with a layer of leather belting or a rubber pad between the top of the timber and the base of the anvil. The bottom of the timbers *b* should be bedded in concrete to insure an even bearing. The objection to the all-timber foundation is its great cost and renewal expense.

31. Elastic foundations have been made by placing the timbers for the foundation in a vertical position. A log large enough in diameter to receive the anvil on its top and to enter the ground 6 or 8 feet is sometimes preferred. The hole is dug 1 foot deeper than is necessary to receive the log. A foot of concrete is then placed in the bottom of the hole, and the log bedded, in a perpendicular position, on top of this. For light drop hammers, a large flat stone is sometimes placed under the bottom of the log. The space about the log in the hole should be filled with earth well tamped into place; the top of the log should be trimmed off to a true horizontal surface. In the case of hammers with openings in the center of the anvil, it is necessary to cut a depression in the center of the top of the log, with a groove leading to the outside to allow scale and dirt to pass off without accumulating under the anvil. When a log large enough for the anvil cannot be obtained, several timbers may be bolted together to form a block of sufficient size. Chestnut or oak timbers are said to be the best for drop-hammer foundations. For hammers with drops weighing 1,000 pounds or more, a masonry foundation is recommended by some builders. A hole is first dug 10 to 14 feet deep, and the masonry built up to within 4 feet of the top. On top of the masonry, oak timbers 4 feet long standing on end are arranged, and bolted closely together. The space around the timbers is then filled with concrete; the anvil is set on top of the oak timbers, as in the case of the foundations already mentioned. In some cases, masonry foundations are built up to within an inch or so of the anvil, and a thick rubber or leather pad placed under the anvil.

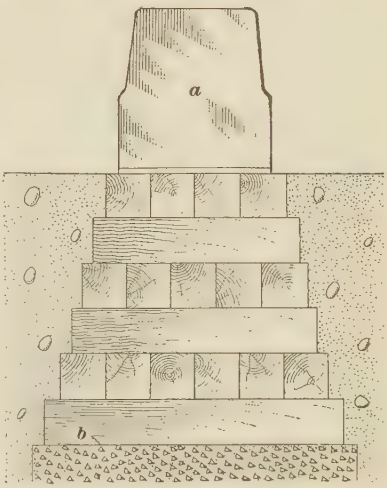

FIG. 27

32. One manufacturer of drop hammers recommends the solid foundation shown in Fig. 28. It is made by digging a hole of the required depth, and lining it with planks, as shown. The space inside of the planks is then filled with concrete. The following proportions for the composition of the concrete are recommended: three barrels of stone, two barrels of gravel, and one barrel of cement. Table II shows the dimensions of the foundations for various weights of the drop, generally called the weight of the hammer.

The dimensions for the foundation of any hammer are found in the same horizontal line as the weight;

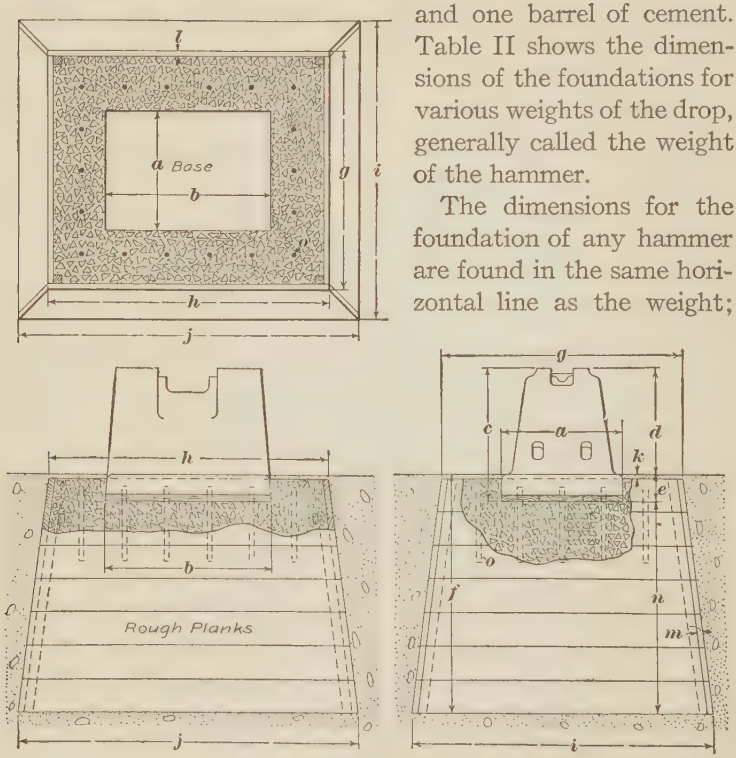

FIG. 28

the letters at the head of the columns correspond to those in Fig. 28. Foundations of this kind have been built without using any elastic material between the anvil and the concrete, with very satisfactory results.

Concrete foundations may be strengthened with reinforcing rods, as shown at *o*, when it is thought the concrete does not supply sufficient strength.

TABLE II

DIMENSIONS FOR DROP-HAMMER FOUNDATIONS

Weight of Hammer Pounds	Foundation Dimensions, in Inches													
	a	*b*	*c*	*d*	*e*	*f**	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n**
400	27	42	$42\frac{1}{4}$	$37\frac{1}{2}$	$4\frac{3}{4}$	64	56	70	72	86	$1\frac{1}{4}$	2	2	$59\frac{1}{4}$
500	27	42	$42\frac{1}{4}$	$37\frac{1}{2}$	$4\frac{3}{4}$	64	56	70	72	86	$1\frac{1}{4}$	2	2	$59\frac{1}{4}$
600	30	$49\frac{1}{2}$	$42\frac{1}{2}$	$37\frac{3}{4}$	$4\frac{3}{4}$	64	60	76	76	92	$1\frac{1}{4}$	2	2	$59\frac{1}{4}$
800	30	$49\frac{1}{2}$	$48\frac{7}{8}$	$37\frac{5}{8}$	$11\frac{1}{4}$	70	60	76	77	93	$1\frac{1}{4}$	2	2	$58\frac{3}{4}$
1,000	40	$57\frac{3}{4}$	45	$36\frac{1}{4}$	$8\frac{3}{4}$	80	80	94	100	114	$1\frac{1}{4}$	2	2	$71\frac{1}{4}$
1,200	40	$58\frac{1}{4}$	$50\frac{1}{8}$	$36\frac{1}{4}$	$13\frac{7}{8}$	84	80	94	101	115	$1\frac{1}{4}$	2	2	$70\frac{1}{8}$
1,400	40	$58\frac{7}{8}$	$55\frac{3}{8}$	$36\frac{1}{4}$	$19\frac{1}{8}$	90	82	96	102	116	$1\frac{1}{4}$	2	2	$70\frac{7}{8}$
1,600	40	$59\frac{1}{4}$	$58\frac{1}{2}$	$36\frac{1}{4}$	$22\frac{1}{4}$	96	84	98	104	118	$1\frac{1}{4}$	2	2	$73\frac{3}{4}$
1,800	$39\frac{1}{2}$	$65\frac{1}{2}$	54	$34\frac{1}{4}$	$19\frac{3}{4}$	104	83	111	106	134	$1\frac{1}{4}$	2	2	$84\frac{1}{4}$
2,000	40	$65\frac{7}{8}$	$58\frac{1}{2}$	$34\frac{1}{4}$	$24\frac{1}{4}$	108	84	112	107	135	$1\frac{1}{4}$	2	2	$83\frac{3}{4}$
2,500	47	71	$57\frac{3}{4}$	35	$22\frac{3}{4}$	118	92	118	121	147	$1\frac{1}{4}$	2	2	$95\frac{1}{4}$
3,000	48	71	$58\frac{1}{2}$	35	$23\frac{1}{2}$	124	92	118	123	149	$1\frac{1}{4}$	2	2	$100\frac{1}{2}$

*NOTE.—Dimensions *f* and *n* to be varied according to the nature of the ground.

33. Comparison of Drop-Hammer Foundations.—It has been found in practice that when the anvils of large hammers are light, it is necessary to use elastic foundations or the force of the blows will cause the foundations to yield. In the case of a large steam hammer installed by the Bethlehem Steel Company, the first foundation, which was made of timber, had very little elasticity. This foundation yielded so that it had to be rebuilt. The second foundation was made very elastic by placing wood shavings and brush beneath the timbers, and no further trouble was experienced.

If the anvil is made heavy enough, it will not have time to move away from the work before the hammer has exerted its full effect, and hence an elastic foundation would not relieve the shock of the blow. With a relatively light anvil, the spring of an elastic foundation allows the anvil to recede when the blow is delivered, and thus prolongs the action of the blow; but it is only on large work that it is especially desirable to obtain this effect.

34. It has been found that a hammer having a solid foundation of sufficient size will do as good work as one having an elastic foundation and dropping about twice as far. The shorter drop also allows the hammer to strike more blows per minute than when operating with a higher drop. Hence, a greater amount of work can be turned out.

It has been found also that when the solid foundation is used practically no repairs are necessary, and a much greater number of hours of work can be done, per year, by a given hammer. It is an interesting fact that wherever the solid foundations have been adopted, and the height of the drops properly adjusted, their use has not been abandoned.

Foundations for steam hammers are usually proportioned to suit the condition of the ground on which the hammer is to be installed. Any foundation dimensions that might be given would therefore be of but limited application.

SWAGING MACHINES

35. Swaging is a cold-forging operation that is performed by pressure applied, removed, and applied again, in rapid succession. At the speeds ordinarily recommended by swaging-machine manufacturers, pressure is applied from 2,000 to 6,000 times a minute, which is almost equivalent to a continuous pressure and causes the metal to flow into the new form. The work done by a swaging machine is round or conical in shape, such as the pointing of pins, the tapering of tubing for bicycle forks, the reduction to exact size of parts of forgings that are to be threaded, etc.

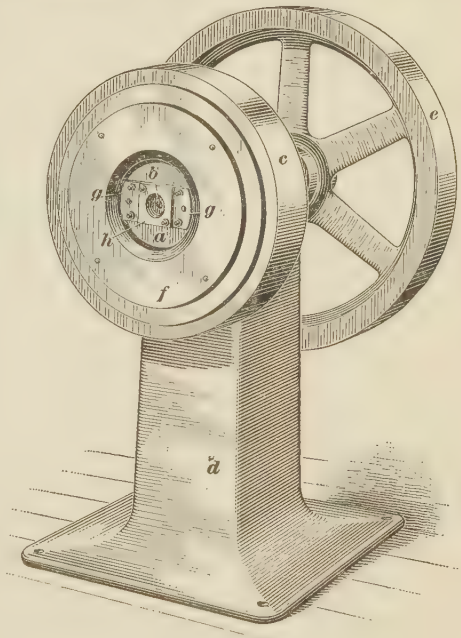

FIG. 29

The front of a swaging machine is shown in Fig. 29. The central part *a* revolves when the machine is in operation, and the stock that is to be swaged is put into the opening *b*. The outside ring *c* is attached to the standard *d* and therefore remains stationary. The rotating head *a* is on the end of a hollow shaft which carries the flywheel *e* on the other end. A similar machine is shown in Fig. 30 (*a*), with the ring *f* and the guards *g* and *h* shown in Fig. 29 removed to show the working parts.

The rollers *a* are supported by the ring *b* around the rotating head *c*. There is a slot running across the center of the revolving head *c*, view (*b*), and two dies *d* and the backers *e* are fitted into this slot. The dies and backers are free to slide

back and forth in the slot and tend to move outwards when the machine is running, but when the backer passes a roller, the die is forced in against the stock. The face of the

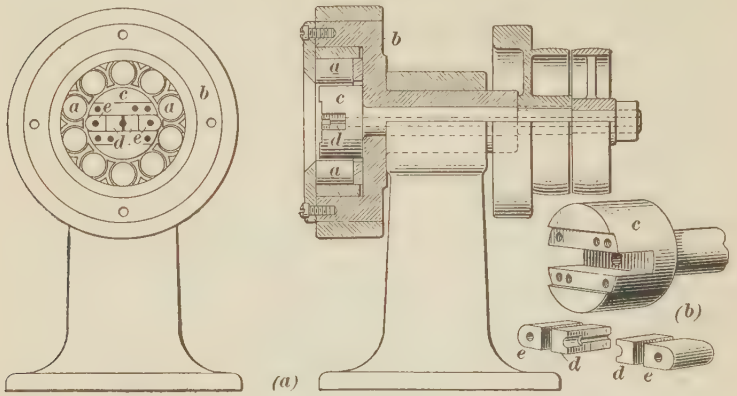

Fig. 30

dies may be flat or they may have recesses the size and shape of the part that is being swaged.

PRESSES

36. Presses are used for forming or shaping metal, for punching holes, and for trimming the fins from drop forgings. One common form of press, shown in Fig. 31, is driven by a belt on pulley *a*, which drives the gear *b* continuously. By depressing the treadle *d*, the clutch *c* is thrown into action and the head *e* is driven down by the eccentric *f*. The upper die is attached to the lower face of the head *e*, and the lower die is carried on a block *h* that fits over the opening *g*. In order to adjust the height of the dies to suit the work, an adjusting nut is provided at *j*.

Work that is too heavy for an open-sided press, such as that shown in Fig. 31, may be done on a double-sided press, such as the one illustrated in Fig. 32. This form of press is frequently used to trim the fin from drop forgings and it is for that reason commonly called a *trimming press*. When trimming small

forgings cold, the forgings are usually punched through the trimming die, which is fastened to the bed of the machine, and fall to the floor. When a small forging is trimmed while hot, the fin is frequently left on the bar from which the forging was made. After the trimming is done, the gate is cut with the side shear *a*. The height of the ram may be adjusted by the nut *b* and the height of the upper shear blade by the nut *c*.

37. In the form of press shown in Fig. 31 the finished work passes out of the way by falling through the opening *g*, to the floor; unless some such means is provided the work must be removed from the dies by hand. The inclined press shown in Fig. 33 has been found convenient for discharging the finished work. The table *a* can be set at any desired angle by adjusting the nut *b*. The stock is passed into the machine from the front, and the finished work slides out through the opening *c* at the back and drops behind the machine. In other respects this press is similar to the one already shown.

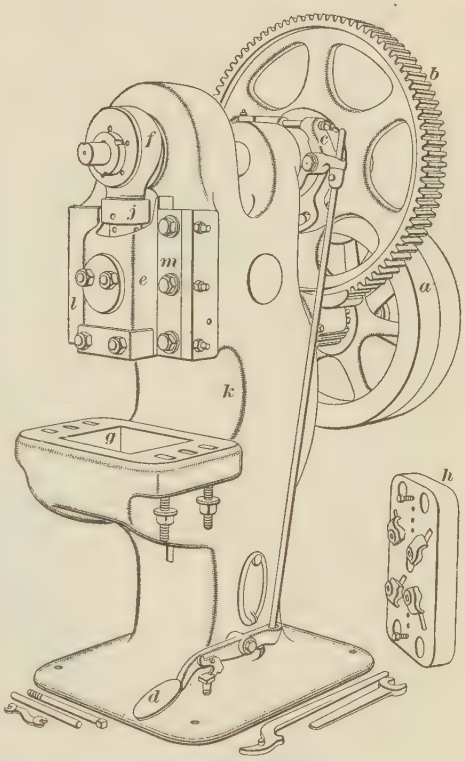

FIG. 31

38. Press Work.—Three operations are performed by presses on the axle the forging of which was described in Arts. **26** and **27;** they are, in the order in which they are performed, trimming, stretching, and bending. The stretching

and bending will, however, be described first and the trimming later. The stretching and bending are done in a press with a two-part fixture. The forging operation does not always make the axle the right length, and the center of the forging is therefore reheated and stretched as may be needed. The principle of the fixture that does the stretching and bending is shown in

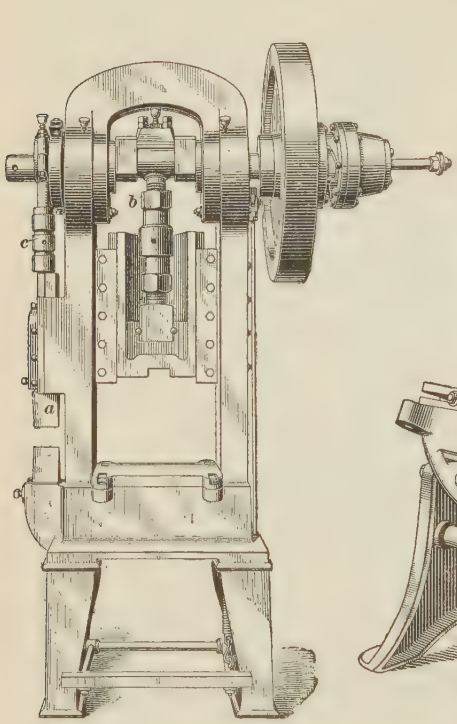

FIG. 32

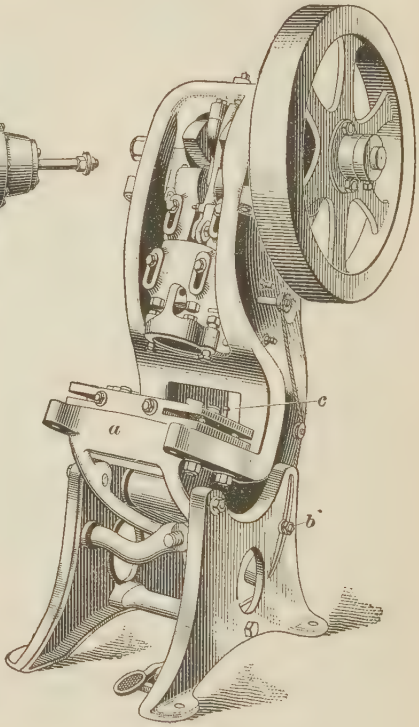

FIG. 33

Fig. 34. Views (*a*), (*b*), and (*c*) show respectively the top, end, and one side of the fixture, and view (*d*) shows the other side. The stretching part of the fixture is shown in the lower part of view (*a*), at the right of (*b*) and in (*c*). The base *a* is fastened to the bed of the press and it carries two slides *b* working in a dovetailed slot in the base *a*. The axle is put in the fixture as shown at *c*, the slides *b* are shoved together until the forked

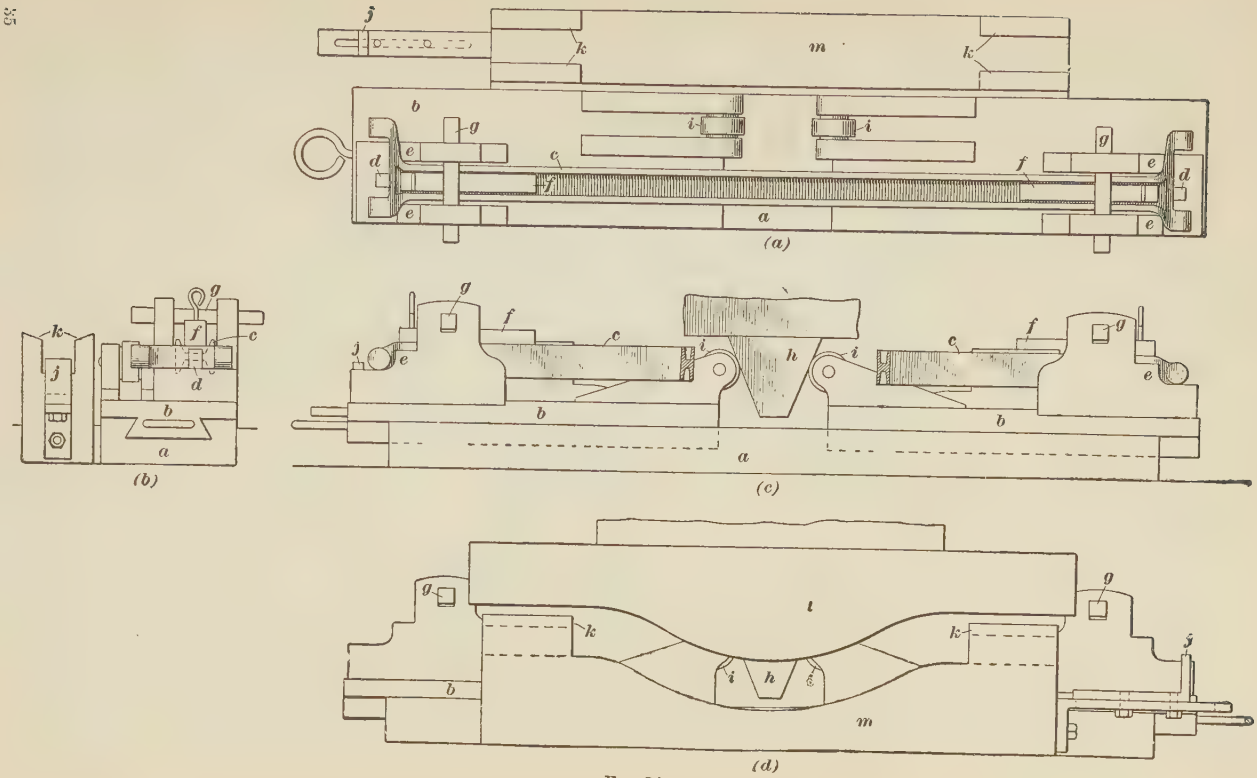
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Fig. 34

ends drop between the stops *d* and the shoulders *e*, and the axle is then clamped in place. The clamping is done by a wedge *f* and a key *g* at each end. The wedge *f* is first laid in the channel of the axle and the key *g* is then driven in over it. This locks the axle in place. The axle is stretched by the wedge *h* which is fastened to the ram of the press. As the ram descends, the wedge *h* is forced down between the rollers *i* and the slides *b* are moved apart, thus stretching the axle. The length of the axle, when stretched, depends on the position of the ram with respect to the fixture when at the bottom of its stroke, and this is adjusted by means of the adjusting nut on the ram *b*, Fig. 32.

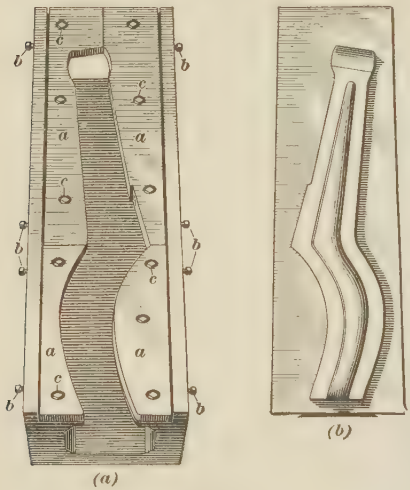

FIG. 35

When the axle has been stretched, it is removed and put in the bending fixture shown at the top of view (*a*), the left of view (*b*), and in view (*d*). The axle is placed against the stop *j* between the guides *k*, which hold it edgewise but do not clamp it, and the upper die *l*, which is fastened to the ram and forces the axle down into the lower die *m*.

39. The trimming of the axles shown in Figs. 21 and 24 differs only in the shape of the trimming dies. The die shown in Fig. 35 is for trimming the axle shown in Fig. 24. The trimming die, Fig. 35 (*a*), is fastened to the bed of the press and the punch, view (*b*), is fastened to the ram. The body of the trimming die is box shaped, so that the axle falls down inside of it and is withdrawn endwise when the fin has been sheared off by the downward motion of the punch. The punch is shaped so as to bear as evenly as possible on all parts of the forging in order that it may not be sprung when it is pushed through the die.

Trimming of large forgings is usually done while they are hot, and the trimming press is therefore set near the hammer in which the forging is finished. The shearing plates *a* of the die are made separate from the body, which may therefore be made of a cheaper material than is required in the shearing plates. The setscrews *b* hold the cutting edges against the forging so that the fin is trimmed off smoothly, and the screws *c* lock the shearing plates securely in position.

UPSETTING MACHINE

40. Upsetting machines are variously called *forging machines*, *bolt-heading machines*, *collaring machines*, etc., depending on the operation that the particular machine is especially

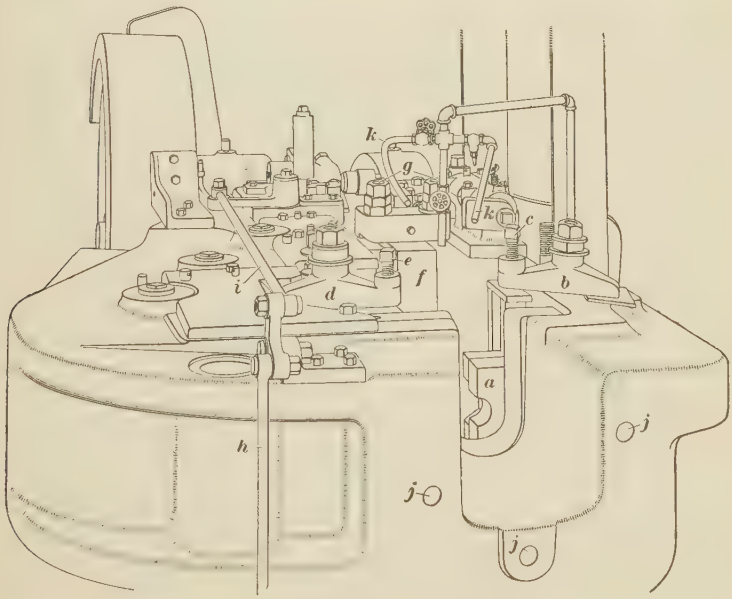

FIG. 36

adapted to perform. The manner in which the forging is done is, however, always the same. When the hot stock is placed in the machine, it is gripped between two dies, one of which is

stationary, which hold it in front of a third die, or plunger tool, that is moved endwise against the stock and forces it into suitable recesses in the gripping dies and the plunger tool. The gripping dies do not always hold the stock securely enough to resist the thrust of the plunger, so it is frequently necessary to provide a back stop of some kind to take the thrust of the plunger. The form of this stop varies with the size and length of the work that is being handled.

An upsetting machine is shown in Fig. 36. The stationary die *a* fits in a suitable recess in the frame of the machine and is held in place by the clamp *b* and setscrew *c*. The die *a* is in this case small, so metal blocks are placed on top of it to give the setscrew *c* a bearing. The outer gripping die, not shown, fits in a recess in a movable head, and is held in place in the head by the clamp *d* and setscrew *e*. When the machine is in operation, the movable gripping die is brought against the stationary die *a*, thus gripping the stock in the recess that is made for it. The plunger *f* carries a die, or tool, that is called a heading tool, upsetting tool, collaring die, etc., depending on the kind of work that is being done. For the sake of simplicity, this die will be called the *plunger tool* regardless of the kind of work that is being done. The plunger tool is down on a level with the die *a* and is therefore hidden by the corner of the frame. The tool is, however, fastened to the ram *f* by bolts *g*. The gripping die and the ram are set in motion by depressing a treadle that moves an operating mechanism through the rods *h* and *i*. The holes shown at *j* are for bolts that secure the back stop, which has been removed from this machine. The dies are cooled, when the machine is in operation, by streams of water from the pipes *k*. The water striking the hot stock also tends to loosen the scale and thus produces a smoother forging than would be obtained otherwise.

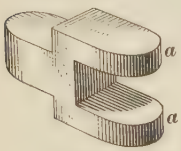

FIG. 37

41. Upsetting-Machine Work.—The clip shown in Fig. 37 is made in closed dies so that no back stop is needed. The dies for this piece are shown in Fig. 38, in which *a* is the

stationary die, *b* the gripping die, and *c* is the plunger tool. The stock of which this clip is made is a rectangular block which is placed, while hot, on the shelf *d* on the stationary die and the

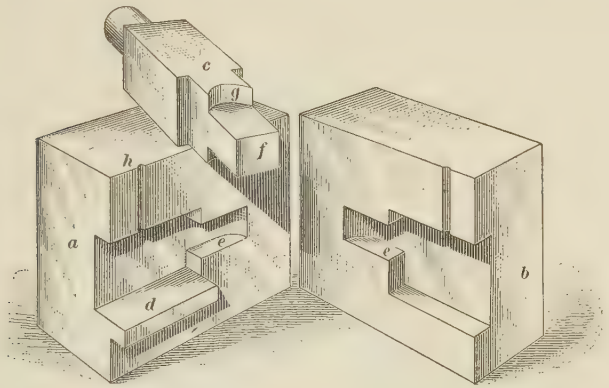

Fig. 38

machine is set in operation. When the gripping die closes on the stationary die, the part of the shelf *d* that projects from the face of the die block fits into the lower part of the opening in the gripping die. The advance of the plunger tool forces the

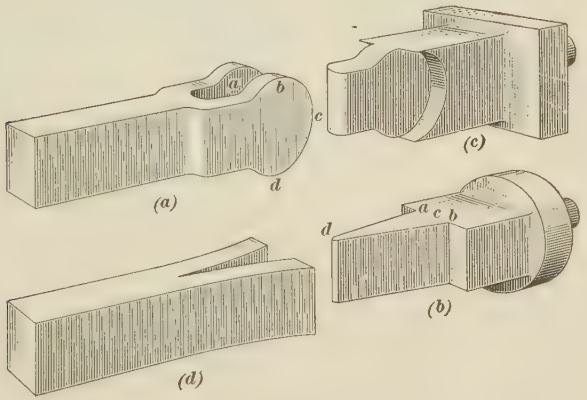

Fig. 39

metal to flow back into the space *e* and along the top and bottom of the projection *f* until it strikes the shoulders *g*. If the metal strikes the shoulder *g* before the plunger has reached the end of

its stroke, the excess metal is forced up into the vent hole *h* and is later cut off. The gripping dies *a* and *b* therefore form the outside of the clip and the plunger tool *c* forms the inside of the forked part and the rounded ends at *a* in Fig. 37.

42. The forked end of a locomotive side rod, shown in Fig. 39 (*a*), is made in an upsetting machine. There are two impressions in the gripping dies and two plunger tools are used. The lower plunger tool is essentially a hot chisel, as it merely splits the end of the rod and prepares it for the forming die which is used afterwards. The stock for the side rod is rectangular in shape and requires no preliminary upsetting. The

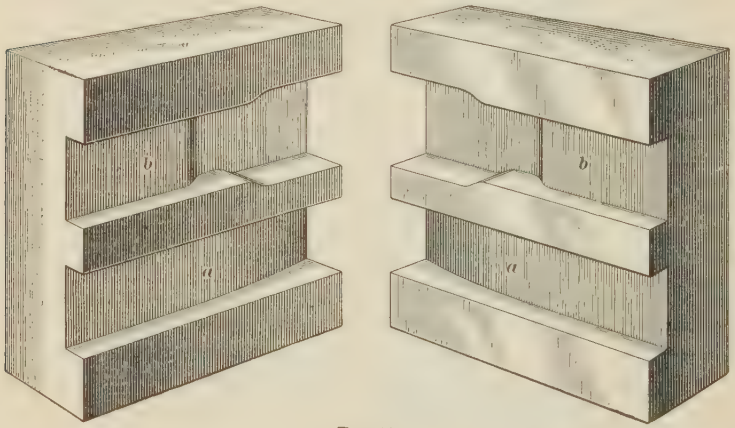

FIG. 40

gripping dies are shown in Fig. 40. The roughing, or splitting, impression is shown at *a*. The depth of the impression at the left end of the die is half the thickness of the main part of the rod. Near the right end of the die the depth of the impression gradually increases until it is equal to half the thickness of the forked part of the rod. The plunger tool with which the end of the rod is split is shown in Fig. 39 (*b*). The width at *a b* is approximately equal to the width of the slot that is to be made in the end of the side rod, and the length of the die from *c* to *d* is approximately the same as the depth of the fork in the end of the rod.

43. When the rod end has been split in the impression *a*, Fig. 40, it is transferred to the upper impression *b*, where the forked end is brought to the finished size and form shown in Fig. 39 (*a*). The plunger tool for finishing the rod end is shown

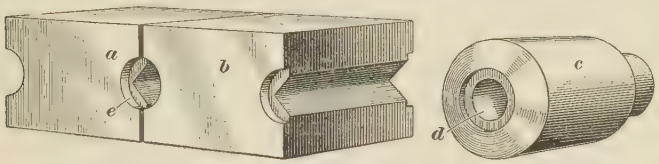

FIG. 41

in Fig. 39 (*c*). This die forms the inside *a* of the fork, view (*a*), and the rounded end *b c d*, all other parts of the rod end being formed by the gripping dies. When the stock is taken from the lower impression in the gripping dies, the end that has been split is the same depth as the body of the rod, as shown in view (*d*), so the plunger tool, view (*c*), not only forms the inside of the fork but it also upsets it so as to form the enlargements at *b* and *d*, view (*a*). A back stop must be used with these dies to keep the stock from being pushed out of the gripping dies by the thrust of the plunger.

44. The dies with which the collar and spindle on the end of an ordinary truck axle are formed are shown in Fig. 41. The gripping dies *a* and *b* are rectangular blocks with an impression cut in each of two opposite faces. These impressions are usually alike, so that when one impression becomes worn or damaged, the die may be turned over and the other impression may be used in its place. The axle is made of square stock which is placed in the recess of the stationary gripping die, where it is held by the moving die. The gripping dies really do little more than hold the stock in line with the plunger tool which is shown at *c*, so a back stop takes the thrust of the plunger.

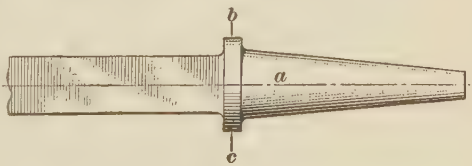

FIG. 42

The conical spindle, shown at *a* in Fig. 42, and the part of the collar at the right of the line *b c*, are forged in the recess *d* of the plunger tool, and the part of the collar at the left of the line *b c* is forged in the recess *e*, Fig. 41, in the gripping dies. A vent hole is drilled in the side of the plunger die at the bottom of the conical hole that forms the spindle. This vent provides an outlet for the air and steam in the die as it is forced over the hot end of the axle. These dies are water-cooled, and water that gets into the plunger die forms steam when the die is forced over the hot end of the axle.

PUNCHES AND SHEARS

45. Punches may be used to make holes in sheet metal, when the holes are not required to be of uniform diameter throughout, or when they can be reamed to the desired size after punching. Shears are used to cut bars or to trim plates to the required size. Alligator, or lever, shears, such as shown in Fig. 43, are especially useful for cutting bar, strap, and scrap

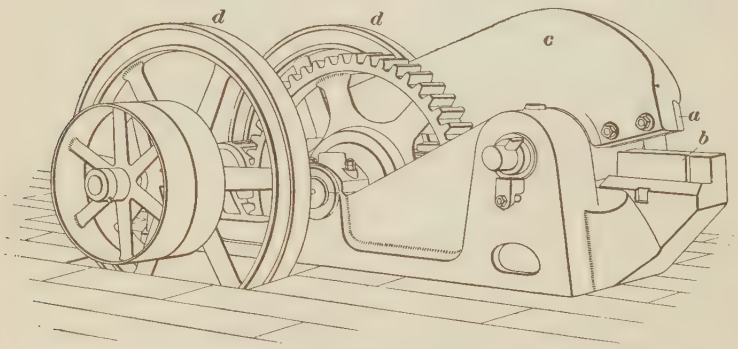

FIG. 43

stock. The stock is cut off between the shear blades *a*, *b*, the lower one of which is stationary and the other attached to the short end of the lever *c*, the long end being moved by a crank or cam. In the shear shown, two flywheels *d* are placed on the main driving shaft, so that their inertia will assist in operating the shear and enable it to cut heavier stock; also, the bar will

be gripped on one edge first, and the cutting will proceed from one side to the other. This enables the shear to cut much larger stock than would be possible if the cutting edges of the blades were to strike both sides of the bar along the entire width.

46. For cutting bars, narrow plates, etc., the shear shown in Fig. 44 is quite frequently used. One advantage of this type is

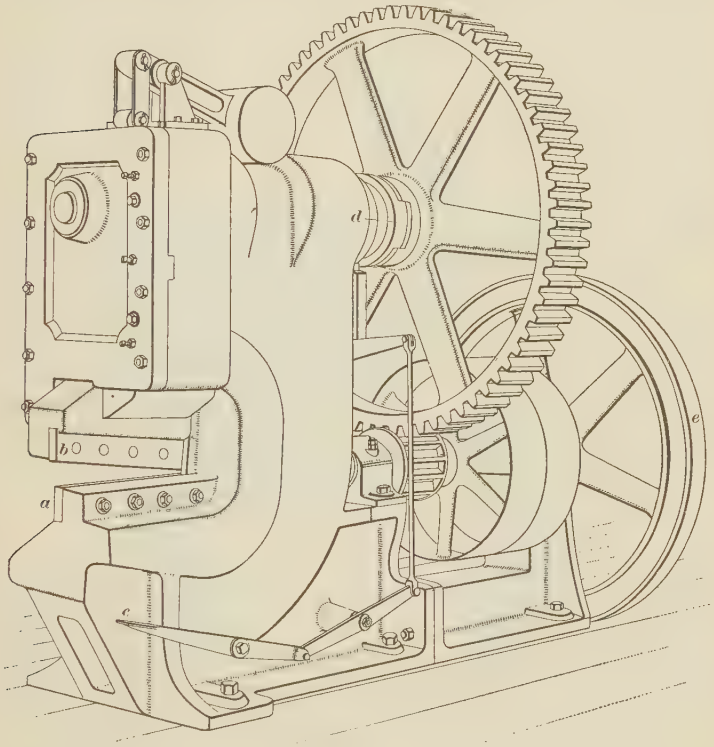

FIG. 44

that it takes up less room than the lever shear. The shear blades *a*, *b* are arranged much as in the lever shear, except that the moving blade *b* is attached to a head, or ram, that descends in a straight line instead of working about a pivot, as in the lever shear. It will be noticed that the blade *b* is set at an angle to the blade *a*, so as to cause the cutting to proceed from

one side to the other and make it possible to cut off larger stock. This is known as giving the blades **shear.**

The operating parts are so arranged that when the treadle *c* is released, the head with the blade *b* always returns to the top of the stroke and remains in that position while the shear is out of use. The pressure of the foot on the treadle *c* throws

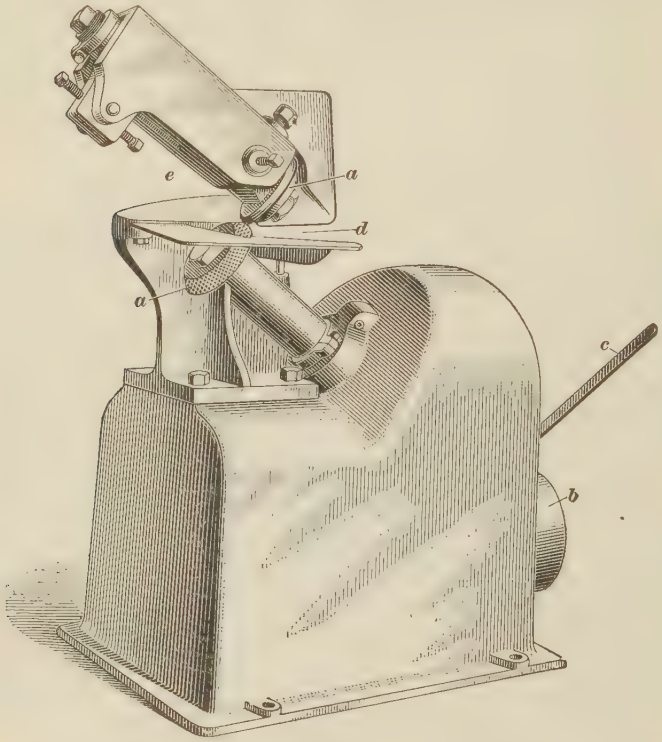

FIG. 45

in the clutch *d*, connecting the head with the driving mechanism and causing the shear to descend and continue to operate until the treadle is released. This shear is also provided with a flywheel *e*, to increase the effectiveness of the machine by storing up energy between cuts and giving it up to the shear when cutting. Sometimes the shear blades *a*, *b* are turned at right angles to the position shown in Fig. 44. This is usually

done with shears intended for trimming the edges of wide plates. Special shears are also made for cutting off structural or rolled shapes.

47. The shears shown in Figs. 43 and 44 cannot be used to make curved cuts nor to cut wide plates, excepting that the shear shown in Fig. 44 may be used to trim the edges of a plate when the blades are set at right angles to the position shown. Such a shear is sometimes called a *trimming shear*. The rotary shear shown in Fig. 45 will cut curves in plates of any width, but it will not cut angles, channels, or similar shapes. The cutters *a* are shaped to cut perpendicular to the surface of the

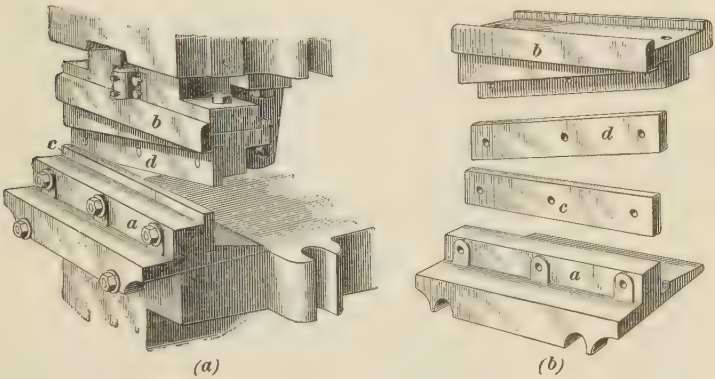

FIG. 46

sheet, but other cutters that will produce an angle cut may be used in their place. The lower cutter is driven by the pulley *b*, through gearing inside the base, and a clutch operated by the lever *c*. The lower cutter therefore drives the plate that is being sheared, and for this reason it is slightly knurled. When a plate is being cut, the part of the plate on the right of the cutter passes through the opening shown at *d*, and that on the left through the space *e*.

48. The shear shown in Fig. 44 is sometimes made convertible, the shear and shear blocks being removable so that a punch-and-die set can be substituted for the shears. The attachments for a shear set are shown in Fig. 46, the assembled

parts being shown in (*a*) and the separate parts in (*b*). The shear blocks *a* and *b* are bolted to the lower jaw and to the ram of the machine, respectively, and the shear blades *c* and *d* are bolted to the shear blocks.

The attachments for the punch set are shown in Fig. 47, the parts being shown assembled in (*a*) and separate in (*b*). The punch *a* is first attached to the punch stock *b* by the coupling nut *c*. The punch passes through a hole in the coupling nut which holds the head *d* against the end of the punch stock. The die set is then assembled by placing the die *e* in the

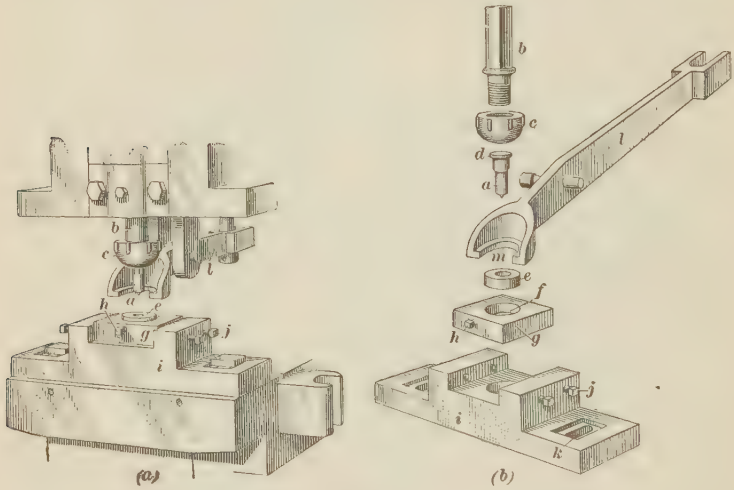

Fig. 47

hole *f* of the die holder *g* where it is held by the setscrew *h*. The die and die holder are then fastened in the die block *i* by the setscrews *j*. When the punch stock *b* has been inserted in the plunger, the die block is bolted to the lower jaw of the machine. In order that the die may be brought in line with the punch, the bolt holes *k* are made slightly elongated to permit adjustment forward and backward. Adjustment sidewise is obtained by means of the setscrews *j*. The stripper *l* is fastened to the frame of the machine, with the semicircular opening *m* around the punch just above the plate that is being punched, and pushes the work off the punch as the plunger rises.

RIVETING MACHINES

49. Some riveting machines form the heads on the rivets by a steady pressure, while others form the rivet head by striking a series of rapid blows. The machine that forms the rivet head by a steady pressure is comparatively large and is therefore especially well adapted to riveting in a shop in which much riveting is done, whereas the riveting hammer, that forms the rivet head by a series of blows, is usually small and is consequently used for riveting that is done away from a shop, or in shops where a comparatively small number of rivets are to be driven and the expense of the larger machine is not warranted. A riveting hammer is shown in Fig. 48. Air at a pressure of about 100 pounds per square inch is brought to the hammer through a rubber hose that is attached to the handle *a*

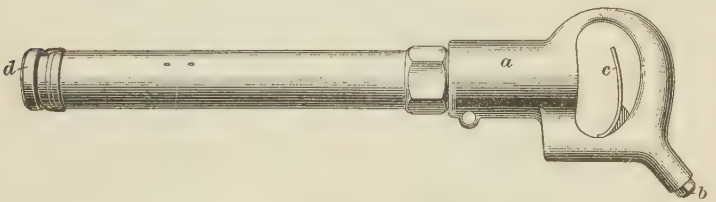

FIG. 48

of the hammer at *b* and the operation of the hammer is controlled by a valve that is operated by the latch *c*. The rivet set *d* is cupped out to form the rivet head. The plunger strikes from 800 to 1,100 blows per minute.

50. The riveter shown in Fig. 49 is larger than the one just described. It is intended to be carried around by a crane, but this form of riveter is also made to remain stationary. The rivet head is formed by the steady pressure of air or steam in the cylinder *a* on the plunger *b*. The pressure is transmitted to the movable rivet set *c* by a system of levers partly shown at *d*. The parts of the riveter are so proportioned that the movable rivet set moves a considerable distance during the first half of the plunger stroke but it cannot be made to exert a very great pressure on the work during this part of the stroke.

During the second half of the plunger stroke, however, the movable set does not move very far but it can exert practically the full pressure for which the riveter is designed. In order that the riveter may head rivets of different lengths and finish the head during the last half of the plunger stroke, the rivet set *c* may be adjusted to different heights. The gauge *e* has two marks showing the position of the end of the plunger at the

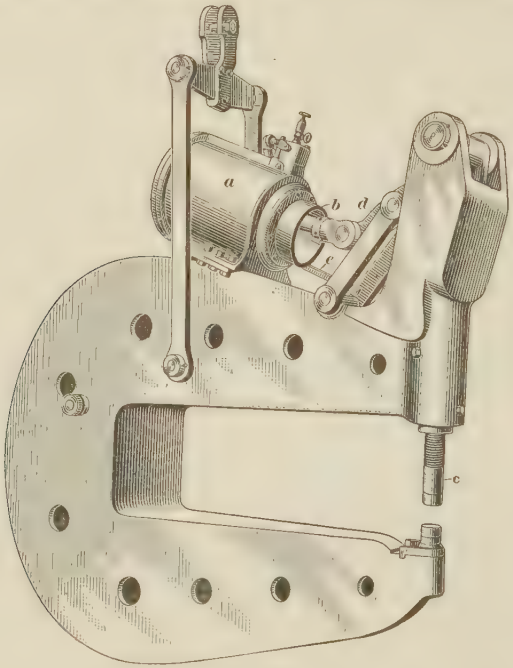

FIG. 49

beginning and at the end of the second half of its stroke. These marks enable the operator to adjust the upper set *c* so that the rivet head is completed during the second half of the plunger stroke when the machine is able to exert its greatest pressure.

51. Riveting.—Rivets in structural work do not, as a rule, have to be driven as hard as when they are to resist steam pressure and hold the joint steam-tight. Some rivets may therefore be driven sufficiently hard while cold to satisfy the

conditions for structural work, but when the joint must be steam-tight it is seldom possible to drive the rivets cold. The pressure required to drive rivets of different sizes depends somewhat on the material of which the rivets are made. A machine capable of exerting the pressure given opposite any given size of rivet in Table III should have sufficient capacity to drive that size of rivet.

TABLE III

PRESSURES REQUIRED TO DRIVE RIVETS

Diameter of Rivets, in Inches			Pressure Required Tons
Driven Cold	Driven Hot		
	Structural	Steam	
$\frac{1}{4}$			12
$\frac{5}{16}$			15
$\frac{3}{8}$			22
$\frac{1}{2}$			31
	$\frac{1}{2}$		20
$\frac{5}{8}$			56
	$\frac{3}{4}$	$\frac{1}{2}$	30
	$\frac{7}{8}$	$\frac{3}{4}$	50
	1	$\frac{7}{8}$	70
	$1\frac{1}{4}$	1	80
		$1\frac{1}{8}$	100
		$1\frac{1}{4}$	125

The holes for rivets should be somewhat large so that the rivet will enter easily. For rivets larger than $\frac{1}{4}$ inch, $\frac{1}{16}$-inch clearance should be sufficient. The length of rivet to be used depends on the thickness of the parts through which the rivet passes and the kind of head that is to be made. In any case, the rivets should be enough longer than the thickness of the parts that are being fastened together to provide stock to make the head and to permit the rivet to upset to fit the hole. The length of rivet usually required for this purpose depends on

the diameter of the hole and the kind of a head that is to be made. For the button head, the length of stock required for the head is $1\frac{1}{4}$ times the diameter of the hole; for the point, or steeple, head, the stock is about 1.3 times the diameter of the hole; for the countersunk head, .8 times the diameter of the hole.

BULLDOZER

52. The bulldozer is a horizontal press for performing bending, forging, and welding operations. One of the most common forms is shown in Fig. 50. In the illustration, a pair of dies *a*, *b* is shown in position for bending the piece of work *f*. The moveable die *b* is attached to the ram *d*, which is driven by the connecting-rods *c*. These machines are made to be driven by a belt, engine, or electric motor, and are used for a very large variety of work, especially for such work as the forgings for car trucks, for agricultural implements, etc. An almost endless variety of work can be done on them, including forging and welding. The stock is generally put in the dies hot, and in most cases simple dies similar to those shown in Fig. 50 are used.

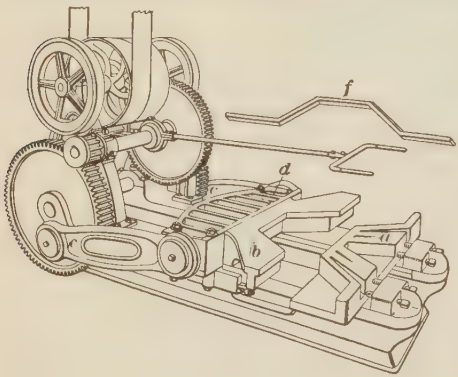

FIG. 50

53. Bulldozer Work.—The **U**-shaped strap shown in Fig. 51 may be formed on a bulldozer. The straight stock is first cut to length and the holes *a*, *b*, and *c* are punched somewhat smaller than the finished size. Holes *a* and *c* are then reamed to size, but hole *b* is left the punched size, so that it can be used in the bending operation. When the strap has been bent into the shape shown, the holes *a* and *c* must be opposite

each other. Hole *b* is half way between *a* and *c* before the stock is bent, and it therefore serves to center the stock while it is being bent. The bending punch, Fig. 52 (*a*), is bolted to the head of the bulldozer and fits into the bending die, Fig. 52 (*b*), which is bolted to the table of the bulldozer. The body *a* of the punch is an iron casting to which the steel wearing plate *b* is fastened. The steel dowel-pin *c* fits into the hole *b*, Fig. 51, in the stock and centers it so that holes *a* and *c* will come opposite each other. The bending die, Fig. 52 (*b*) is also an iron casting. The opening *d*, into which the stock is pushed for bending, does not need to be as deep as the piece that is being bent. It need only be deep enough to make the stock that is being bent lie close to the side of the punch. There is a considerable force tending to drive the parts *e* and *f* apart when the die is in use, and these parts are therefore

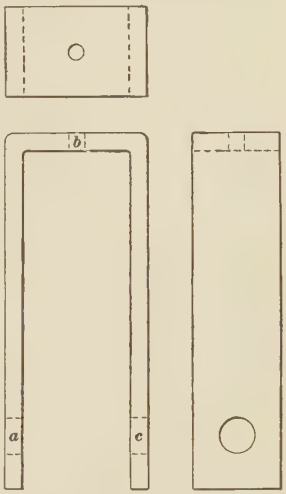

FIG. 51

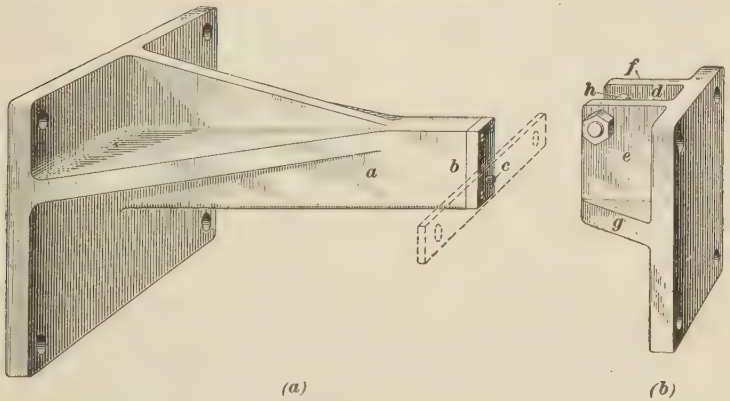

FIG. 52

strengthened by ribs *g* and by the tie-bolt *h*. The tie-bolt is placed high enough to allow the punch to pass under it.

FORGING DIES

FORMS OF FORGING DIES

DROP-FORGING DIES

PRINCIPLES OF DROP FORGING

1. The object of this Section is to explain the forms of forging dies in use and the methods of making them. A **drop forging** is one made between dies by a machine employing the force of a dropped weight. By the use of drop-forging dies it is possible to make forgings that would otherwise be impractical owing to the great expense. Drop forgings are made of any weight from a fraction of an ounce to over a hundred pounds, and forgings uniform in quality are produced in large quantities. The advantages of drop forgings are low cost; uniformity, permitting them to be used interchangeably; strength; ductility; and a pleasing general appearance. Drop forgings are generally made of low-carbon steel, although they are also made of alloy steel, wrought iron, tool steel, copper, and bronze.

2. Classes of Drop-Forging Dies.—One of the simplest sets of drop-forging dies is shown in Fig. 1. It consists of the upper die *a*, which is secured to the hammer, and the lower die *b*, which is secured to the anvil. The recesses in the dies are indicated by the dotted lines *c*. The die recesses are generally spoken of as impressions It will be noticed that the deeper impression is in the upper die. This is generally so, owing to

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the fact that in practice it has been found that the metal then more readily fills the impression in all parts. The line *d*, where the upper and lower dies come together, is known as the *joint line* of the dies. The form of the joint line depends on the shape of the work to be made. Drop-forging dies may be divided into two classes: those having a straight joint line as *d*, Fig. 1, and those whose joint line consists of two or more straight lines that lie at an angle to each other, or a combination of straight lines or curves. It is essential that there be little or no side thrust from the dies to the hammer guides when in action; that is, the dies should be balanced. This is readily done in the case of those dies having a straight joint line by making the dies so that the joint will be at right angles to the center line of the hammer; that is, making the joint line horizontal.

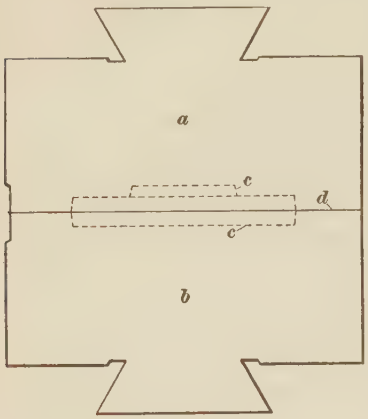


FIG. 1

Dies of the second class may be subdivided into those in which the side thrust is balanced by choosing a suitable angle for the lay of the work in the die, and those in which the thrust is balanced by the addition of a part to the die for this purpose.

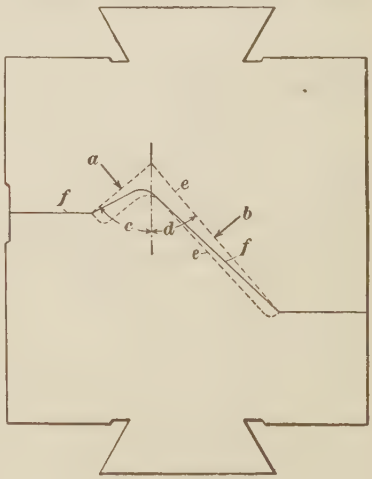


FIG. 2

3. In Fig. 2 is shown a pair of dies for a right-angle bend, in which the thrust is balanced by choosing a suitable angle for the lay of the work.

In this case, the thrust in the direction *a* is offset by a thrust *b*, as shown by the arrows. The amount of the thrust in either direction may be changed by changing the angles of the die. In case the angles *c* and *d* were equal, the thrust would be away from the side *b* which has the largest area. As the greatest thrust occurs during the first few blows, the lay should be made so the thrust will be balanced at that time. In the figure, the dotted lines *e* represent the depressions in the dies and the line *f* is the joint line.

In Fig. 3, a pair of dies is shown in which the thrust is balanced by making the dies so that the part *a* will back into the part *b* and create an equal thrust in the opposite direction. As before, the depressions in the dies are indicated by dotted lines *c*.

The surface of the dies that meet when a blow is struck is known as the **striking surface.** Dies should be so made that the striking surface will be uniform around the impressions.

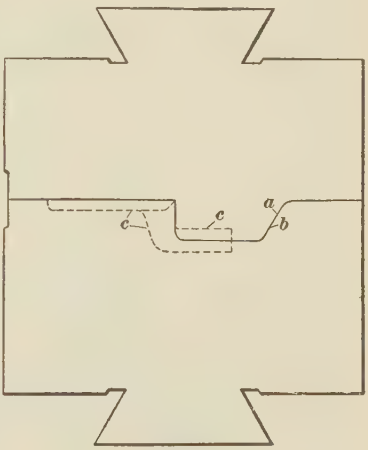


FIG. 3

4. Die Parts.—It is only in the case of the simplest forgings that the work may be finished in a single die recess. Four recesses may be necessary, the *fuller;* the *breakdown, bending impression, edger,* or *side cut;* the *roughing impression;* and the *finishing impression.* To these may be added the *cut-off* in case the forgings are to be cold-trimmed. Some parts of the finished forging are thicker than others, and, as the work is forged from a bar of uniform thickness throughout, the stock must usually be first roughly shaped to fill the die impressions. The die recess known as the **fuller** is of such form that when the stock is forged in it the stock will fill the roughing and finishing impressions when struck. The stock is drawn out in this recess in the same manner as the blacksmith

draws out stock under the trip hammer. When the fuller is of such shape that the stock may be rolled in it, it is frequently called a *roller*. Again, when a die has a fuller but no breakdown, the fuller is sometimes spoken of as a breakdown. Fullers are very frequently required in drop-forging dies. In Fig. 4 a forging is shown that is made in the dies shown in Fig. 5. In Fig. 5 (*a*) is shown the top die, in (*b*) the bottom die, and at *a* the fuller. In Fig. 6 (*a*), the forging is shown as it leaves the fuller. After being shaped in the fuller, it is often necessary to distribute the metal by bending and otherwise shaping it in a side

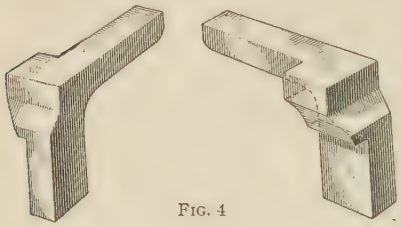


FIG. 4

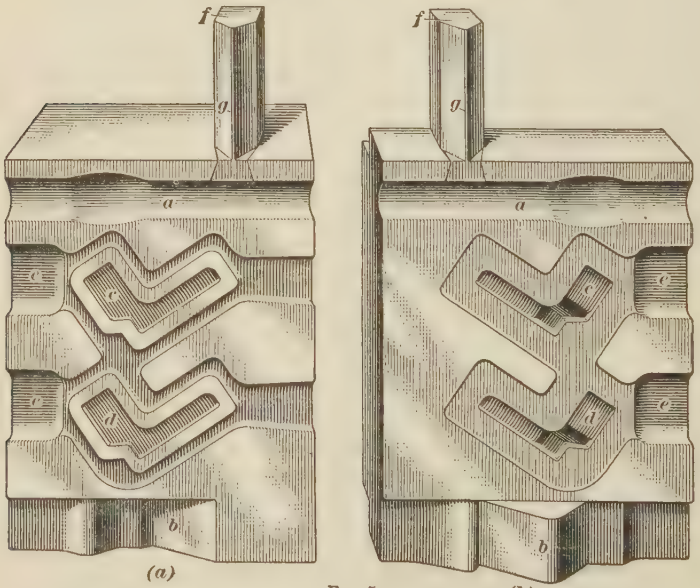


FIG. 5

impression called the **breakdown, edger, bending impression,** or **side cut.** As a rule, the breakdown is so located that when the work is in it the work stands at right angles to

the position it occupies when in the finishing impression. The breakdown is located on the right-hand side of the die, as it is easier for the operator to swing the bar on that side. In Fig. 5 the breakdown is shown at *b*, and in Fig. 6 (*b*) the forging is shown as it leaves the breakdown.

5. After being shaped in the breakdown, the forging is formed nearly to its finished dimensions in the roughing impression *c*, Fig. 5, and then finished in the finishing impression *d*. In Fig. 6 (*c*) the work is shown as it leaves the finishing impression. In some cases the roughing impression is omitted and the forging is both roughed and finished in the one impression. It is much better however, except in those cases where there is very little forging to be done, to use the two impressions, as the dies will last much longer, the severe duty of completely forming the forging being saved from the finishing impression. In the case of large forgings the finishing impression is made on a separate set of die blocks, and the dies are secured to another hammer located so that either hammer can conveniently be used. In the case of small forgings made in large numbers, two finishing impressions are often made in the dies. When this is done the dies last longer, for after one of the finishing dies wears out another is available.

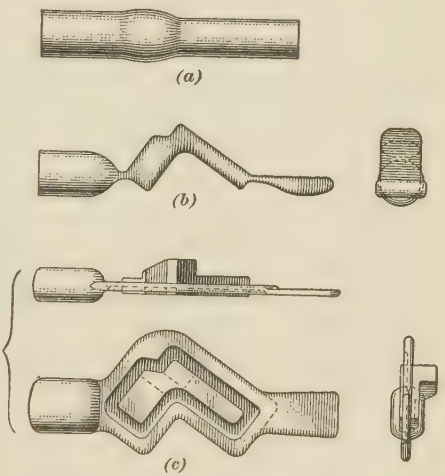


FIG. 6

6. Drop-Hammer Die Fastenings.—The manner of fastening drop-hammer dies depends somewhat on the character of the work being done. For heavy forging operations the dies are usually fastened with two keys, one on each side of

a dovetail or feather on the back of the die. Sometimes two slightly tapered keys having straight sides are driven from opposite directions, but on the same side of the die, so as to clamp the die with an even parallel bearing on both sides. For light work, with forming dies operating on thin metal, either hot or cold, the lower die is usually held by means of poppets with adjusting screws. The use of these poppets permits considerable adjustment of the die; but they would not be strong enough to hold the dies in place for heavy forging. A pocket is sometimes formed in the anvil face, so that a suitable projection on the die may fit into this pocket and thus aid in keeping it in its proper position.

7. Fin Formed on Forgings.—If the work being forged is of circular cross-section, and so formed in relation to its axis that the piece can be revolved, as, for instance, the handle

FIG. 7

shown in Fig. 7 (*a*), the forging dies will be made as shown by the cross-section in Fig. 7 (*b*). The form in both dies corresponds to the form to be given to the work, but the corners *a* are rounded, so as not to scar the work. By rotating the work as it is being forged, it will finally be brought to the desired circular cross-section, as indicated by the dotted circle at *b*, and there need be no burr on the finished forging.

8. In the case of work that is not round in cross-section, or which does not have a straight axis, it is impossible to turn the piece in the die, and, hence, it must be forged to shape without rotation. Dies are made that can be used for a series of impressions or operations, some parts of the dies acting on the edges, and others on the faces of the work. The finishing die always squeezes out some metal on the edge of the work, as shown in Fig. 8 (*a*). This metal formed on drop-forged work is known as the **fin**, and provision is usually made for it by a

groove in the die, known as the **flash**, as shown at *a*, Fig. 8 (*b*). The fin is also sometimes called the flash. On the average-size dies, the flash is a flat shallow recess about $\frac{1}{64}$ inch deep and $\frac{5}{8}$ inch wide. On larger dies the flash is deeper and wider. The upper die is usually made with a **back flash**, or **gutter**, as shown at *b*, in addition to the flash. This back flash is generally milled about $\frac{1}{4}$ inch from the impression and about $\frac{3}{64}$ inch deep. It receives the excess metal after it is squeezed through the flash. No flash is milled in the roughing impression, as the metal does not quite fill the recess when struck. The finishing impression only is provided with flash and back flash. In Fig. 8 (*a*), *c* is the fin formed by the flash, and *d* the fin formed by the back flash.

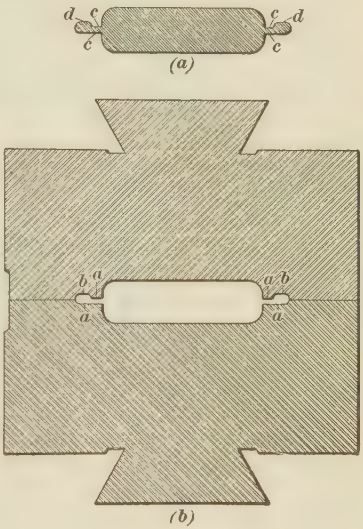


FIG. 8

9. Gate and Sprue. Drop forgings are usually made complete while still a part of the original bar. The bar is thinned down where it connects with the forging, and the channel in the die that forms this connection is known as the gate. The gate extends from the edge of the die block to the front end of the impression. Each impression must have a gate. The size of the gate should be such that it will support the forging while being worked. The gate is enlarged at the edge of the die block to form an opening called the sprue, shown in Fig. 5 at *e*. This sprue is large enough to admit the rough bar. In Fig. 5 the gate is omitted owing to the fact that the forging is small. In this case, the flash extends to the sprue and serves the purpose of the gate.

10. Severing Work From Bar.—The fin is removed from the forging in a separate operation. If removed while hot, the operation is known as **hot trimming**. If the forgings are

hot trimmed, they are cut clean from the bar on the trimming press, and the fin that remains attached to the bar is removed by a cut-off attached to the bolster plates of the trimming press. In this case, the forging dies do not require a cut-off. If the fin is not removed till cold, the operation is known as **cold trimming.** Most small forgings are cold trimmed. When cold trimmed, the forgings are severed from the bar when hot by the use of a cut-off forming part of the forging dies. The cut-off is generally placed across, or dovetailed to, one of the two rear corners, wherever there is the most room, as shown in Fig. 5, at *f*. It is made by forming a chisel-shaped part on each die. The edges of the cut-off are not, however, made sharp, but are made with a face *g* about $\frac{1}{8}$ inch wide so that they will last long in use. In some cases, as when dovetailed into the die block, the cut-off is made of separate pieces set into the dies so that they may be readily replaced in case they are broken.

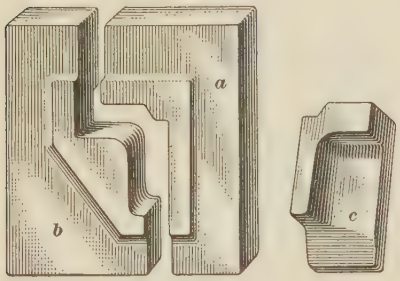


FIG. 9

11. Removal of Fin. In Fig. 9, the cold-trimming die and punch used to trim the fin from the forging shown in Fig. 4 are shown. The die consists of the two parts *a* and *b*, and *c* is the punch. The die is in two parts owing to the fact that it may then be more readily made, and it also provides a means of adjustment for wear. It is secured to the bed of the press by means of keys, bolts, or clamps. The punch *c* is secured to the ram of the press. In operation, the forging, with the fin attached, is placed over the opening in the die, after which the punch is caused to descend and force the finished forging through the die. The forging drops through the base of the machine. The fin remains on the top of the die or sticks to the punch and rises with it. Generally, strippers are arranged to remove the fin from the punch as it ascends. The fin is then brushed aside and the operation is continued.

When the forgings are hot trimmed, the trimming die and cut-off are generally both attached to the bolster plate of the press. In Fig. 10, one form of bolster plate is shown. It is

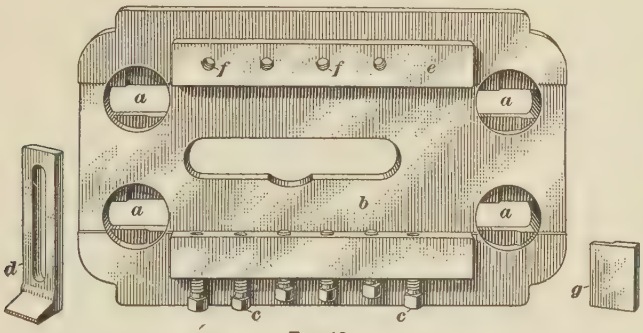


FIG. 10

secured to the bed of the press by means of the holes *a*, and the trimming die is set in the recess *b* and held in place by the screws *c*. The cut-off tool *d* is next attached to the part *e* by means of screws that fit in the holes *f*, and the cut-off tool *g* is attached to the ram of the press. In operation, the forging is punched clean from the fin while hot, and the fin is then severed from the bar by means of the cut-off. The hot-trimming press should usually be located close to the hammer and furnace; for, as a rule, the forging is trimmed, without reheating, as soon as it is taken from the hammer.

EXAMPLES OF DROP-FORGING DIES

12. Dies for Open-End Wrench.—The process of drop forging is illustrated by the making of an ordinary open-end wrench, shown in Fig. 11. A bar of suitable size to form the piece is selected and a portion of it may be formed under a power hammer, or between suitable drop-forging dies, so as to leave sufficient material for the head, while the handle is narrowed somewhat. The dies for doing the work are shown in Fig. 12. The piece is first placed in the die opening *a*, which will form it

FIG. 11

as shown at *f*, the end of the die acting as a fuller to spread the stock for the head. The work in all cases is held by the sprue *k*. After the piece has been struck one or two blows

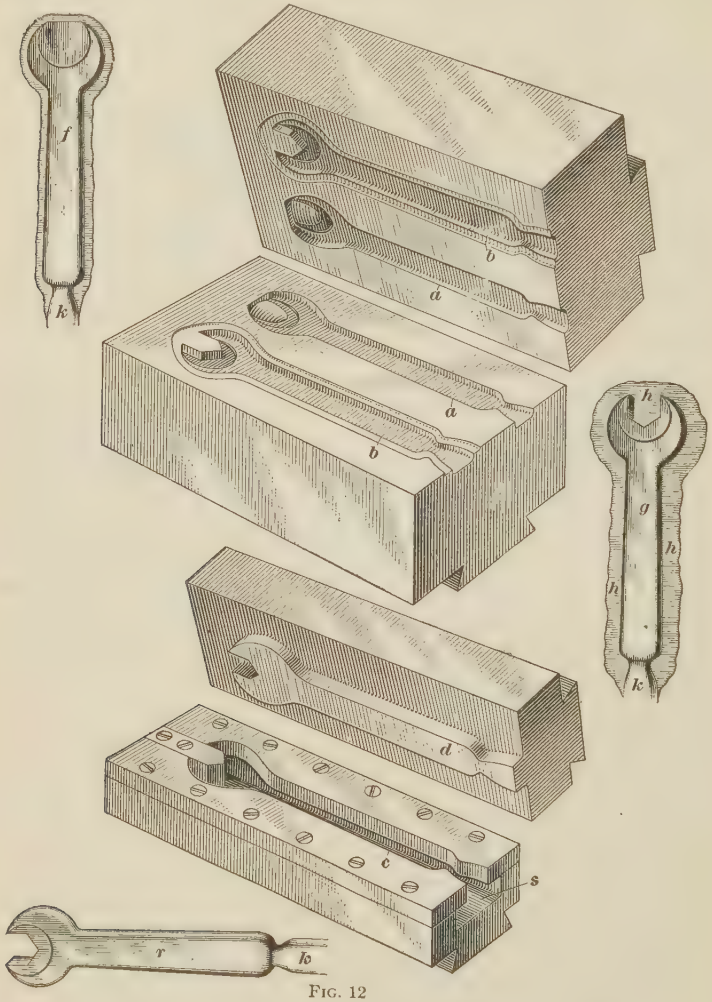


FIG. 12

in the opening *a*, it is placed in the opening *b*, and struck several successive blows. This brings the entire wrench to the finished form, except for the fin shown at *h* in the piece at the

right of the dies, the wrench being shown at *g*. The piece is now placed in the trimming die *c* and struck by the punch *d*. This drives the wrench into the space *s*, from which it is removed

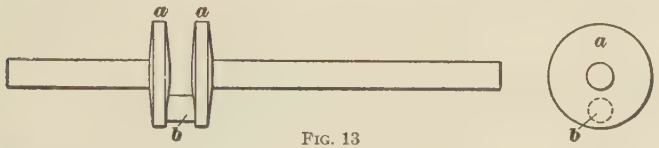


FIG. 13

endwise, in the form shown at *r*, and leaving the fin on the top of the die block. The sprue *k* is then cut off, which completes the forging. Instead of forming a portion of the stock under a power hammer, or between separate dies, a fuller similar to the one shown in Fig. 5 at *a* may be made a part of the dies and used to shape the stock. The trimming die *c*, Fig. 12, is built up of four pieces that are screwed together as shown. This is done because the die can then be more easily made, and also because, when one part becomes broken or worn out, it may be replaced without making an entire new die.

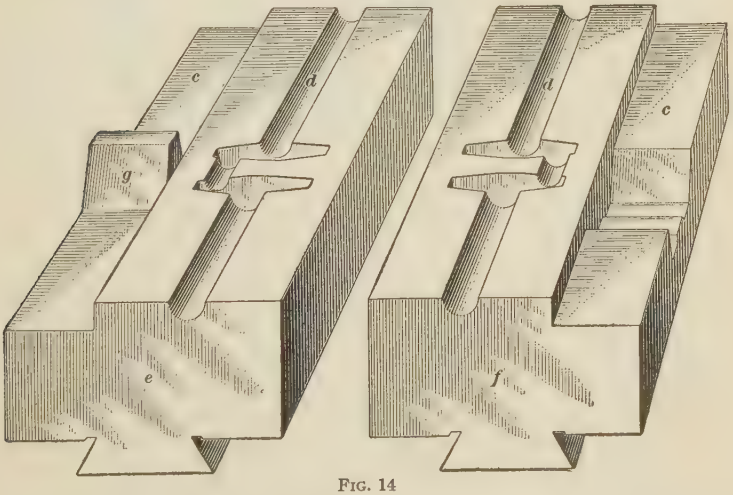


FIG. 14

13. Dies for Single-Throw Crank-Shaft.—An interesting example in drop forging is the making of the single-throw crank-shaft shown in Fig. 13. In Fig. 14, the dies for

breaking down the stock and forming the disks *a*, Fig. 13, pin *b*, and adjacent parts of the forging are shown. The remainder of the ends of the shaft are forged under an ordinary trip hammer. By the use of the short dies shown, a small amount of stock is acted on and the forging can be made under a lighter hammer than would otherwise be required. The forging is made from square stock, by passing it back and forth from the breakdown *c*, Fig. 14, to the roughing impression *d*, a tong hold having first been forged on its end. All the corners of the roughing impression are well rounded to prevent cold

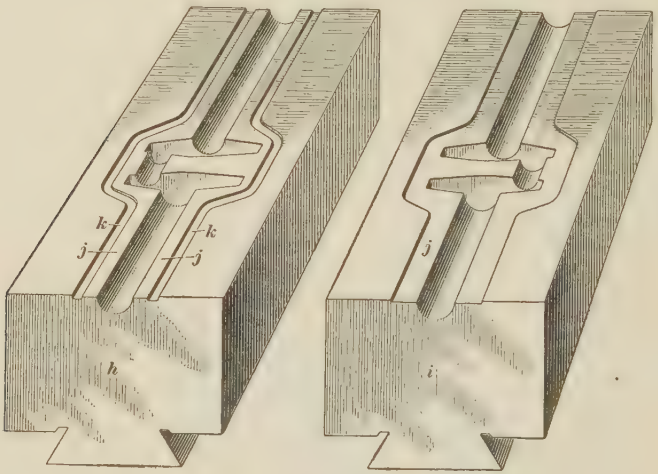


Fig. 15

shuts. In the figure, *e* is the top die and *f* the bottom die. The part *g* of the top die is made separately and dovetailed into the side of the block.

14. After the stock is distributed in the roughing impression, it is placed in the finishing dies shown in Fig. 15 and forged to size by a few blows of the hammer. In the figure, *h* is the top die and *i* the bottom die. The flash is shown at *j* and the back flash at *k*. The impression in the finishing die is like that of the roughing impression, except that the corners are not rounded so much. Two hammers are necessary for this job, one for the

roughing dies and one for the finishing dies. These should be located near each other and near to the furnace, so that no time will be lost in going from one to the other. The trimming

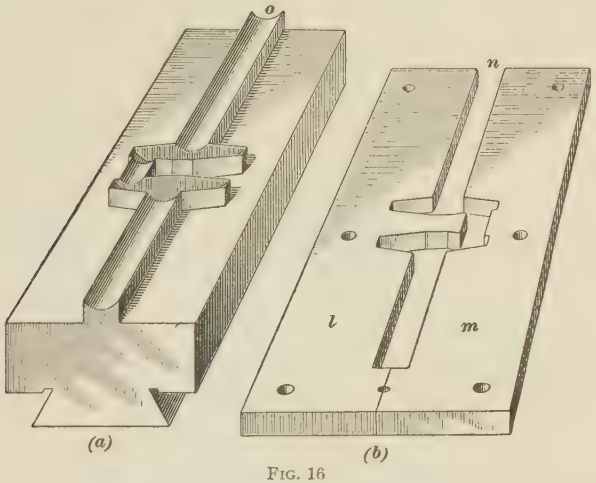


FIG. 16

punch is shown in Fig. 16 (*a*), and the trimming die in (*b*). The die is made in two parts *l* and *m* and is left open at the front end *n* for hot trimming. The punch is milled out as shown at *o* to receive the forging so that it will not bend during the trimming operation. As the trimming is done hot, and generally without reheating after forging, the press should be located near the hammer on which the finishing is done. After the trimming is done, the crank-shaft is finished by drawing out the ends of the stock under a trip hammer.

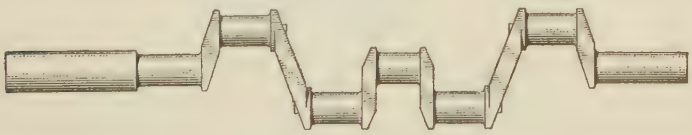


FIG. 17

15. Dies for Four-Throw Crank-Shaft.—The forging of the four-throw crank-shaft shown in Fig. 17, unlike that of the single-throw shaft just explained, can be most readily

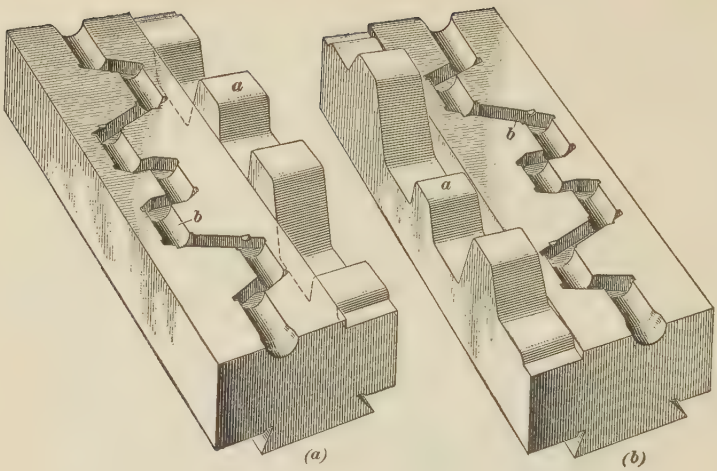


FIG. 18

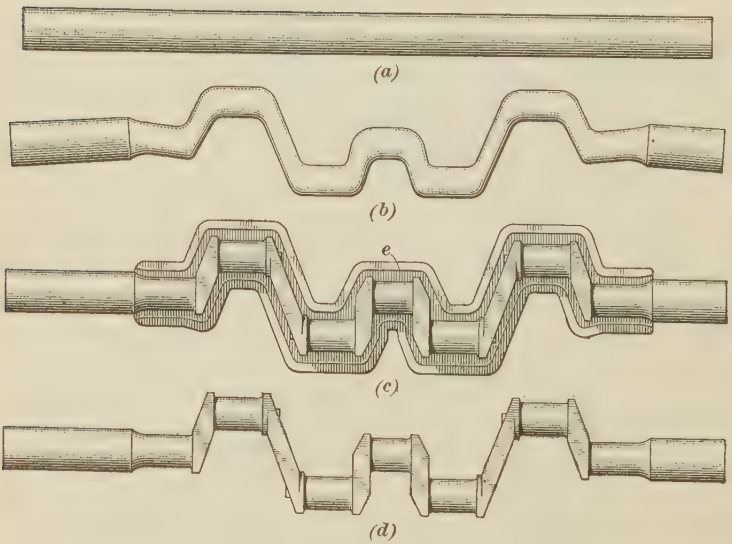


FIG. 19

completed in the dies; for in this case nothing would be gained by forging the ends under a trip hammer. In Fig. 18, the dies for breaking down and roughly forming the shaft are shown, the top die being shown in (*a*) and the bottom die in (*b*). The stock from which the shaft is forged, which is a little larger in diameter than the bearings, is shown in Fig. 19 (*a*). In Fig. 18, the breakdown is shown at *a* and the roughing impression at *b*. The roughing impression is shaped like the shaft except that the corners are slightly rounded to prevent cold shuts. In Fig. 19 (*b*), the stock is shown after being forged in the breakdown, and in (*c*) it is shown as it leaves the finishing impression. The finishing is done by a few blows of the hammer after

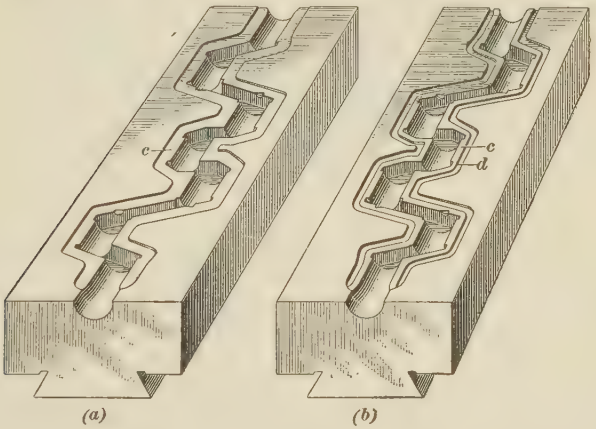


FIG. 20

locating the work properly in the finishing dies shown in Fig. 20, the die shown in (*a*) being the bottom die and that in (*b*) the top die. In the figure, the flash is shown at *c* and the back flash at *d*. The corners are not rounded as much as those of the roughing impression. As explained before, no flash or back flash is provided on the roughing impression.

16. Two hammers are required to forge this shaft, one for the roughing dies and one for the finishing dies. Both of these should be located within easy reach of the heating furnace, for convenience in operating. In case only a few of the shafts are

to be made, or where less accurate work would be satisfactory, the finishing dies may be omitted and the roughing and finishing may be done in the same impression. In that case, only one hammer is required to forge the shaft, and the cost of forging is materially reduced. The fin *e*, Fig. 19 (*c*), is removed by the

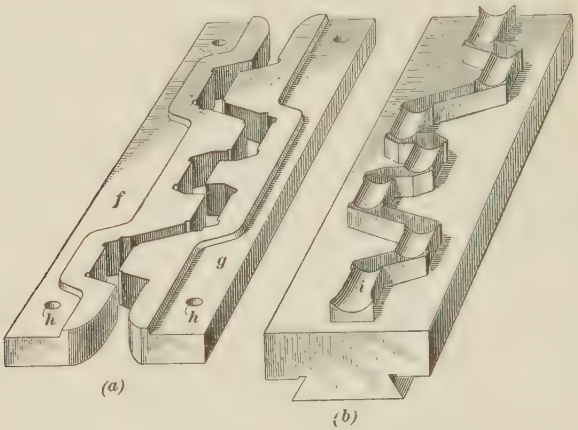


FIG. 21

use of the trimming die and punch shown in Fig. 21 (*a*) and (*b*), respectively. The trimming is done hot. The die is made in two parts *f* and *g*, for convenience, and these parts are attached to the bed of the press by means of bolts that pass through the holes *h*. The punch is milled out as shown at *i* to receive the forging and to guide the shaft while pushing it through the trimming die. As the shaft is trimmed hot immediately after the forging is finished, the trimming press should be located reasonably near the hammer on which the forging is completed. The shaft as it leaves the trimming press is shown in Fig. 19 (*d*). After trimming, the shafts may be straightened on a hydraulic press, or in some other convenient way, and then removed to the machine shop, where they are finished to size.

17. Dies for Flanged Piece.—Suppose the forging, two views of which are shown in Fig. 22, is to be drop forged. This may be done by the use of the set of dies shown in Fig. 23; in (*a*) the bottom die is shown and in (*b*) the top die. This

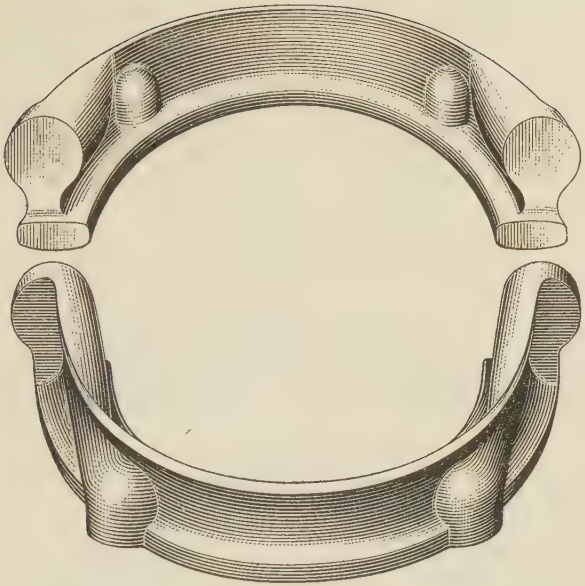


FIG. 22

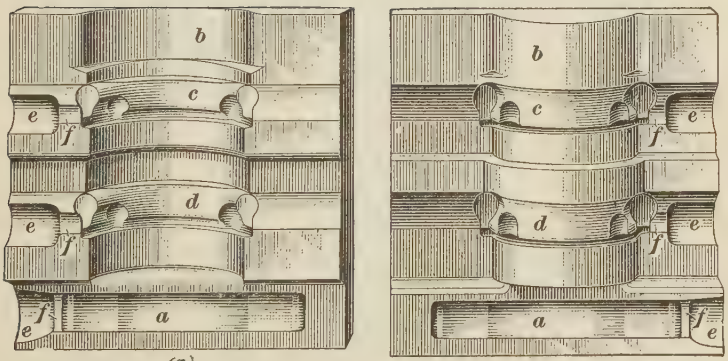


FIG. 23

forging is made of round bar stock, which is first rolled in the fuller *a*, after which it is broken down in the breakdown *b*. The stock is then formed nearly to shape in the roughing impression *c*, after which it is finished in the impression *d* by a few blows of the hammer. The sprues and gates for the various impressions are shown at *e* and *f*, respectively. The stock as it leaves the fuller is shown in Fig. 24 (*a*); in (*b*) it is shown as it leaves the breakdown; and in (*c*) as it leaves the finishing impression. The fin *g*, shown in (*c*), is removed by

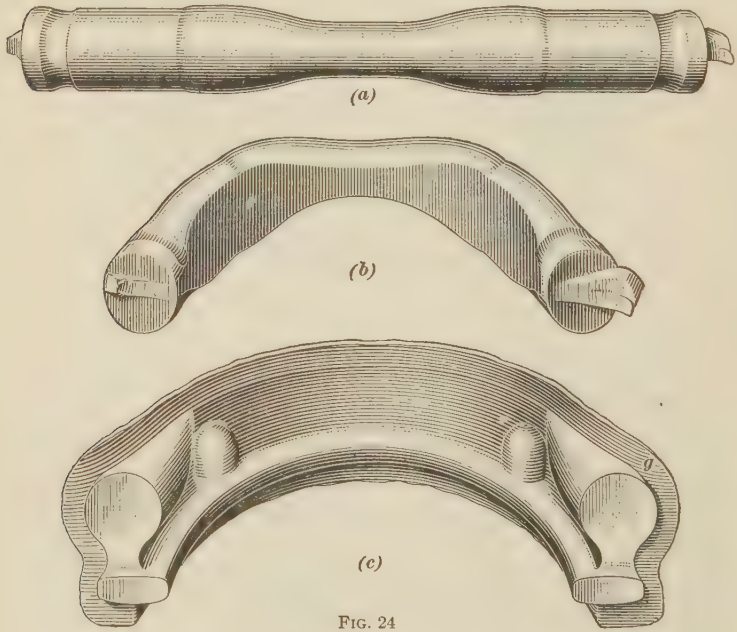


FIG. 24

hot trimming, using the trimming die shown in Fig. 25 (*a*) and the trimming punch shown in (*b*). The die is made in two parts *h* and *i*, which are doweled together by the pin *j* of the part *h*, which fits into a dowel hole in the part *i*. The die parts are clamped to the bolster plate of the press. The part *k* of the punch is made to fit into the ram of the press. After the work is trimmed, the fin is cut off the bar by the use of the cut-off, or side shear, attached to the press as previously explained,

and the end of the remainder of the bar is again placed in the furnace. Another forging is then made from the bar. Usually several bars are heated at the same time so that another bar will always be at the proper heat for forging as soon as one forging is finished.

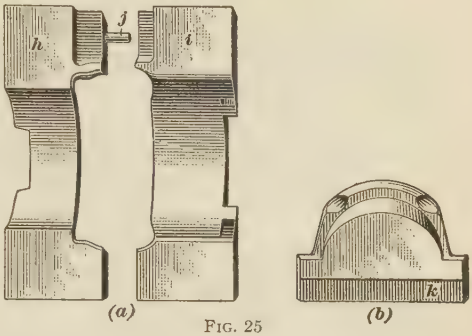


FIG. 25

18. Two-Operation Dies.—It is not always possible to make one set of forging dies produce the work, and in other cases the work cannot readily be shaped with a single set. In both of these cases, it is generally possible to do the work by first making a preliminary forging, in one set of dies, and then finishing the forging in another set. When this is done, the work is spoken of as a two-operation job, and the dies used as two-operation dies. The forging of the steering knuckle shown in Fig. 26 is an example of work that can be most readily forged in two-operation dies. In Fig. 27, the dies in which the work is first forged are shown, the bottom die being shown in (*a*) and the top die in (*b*). The breakdown is shown at *a*, the forming impression at *b*, and the work as it leaves the dies is shown in Fig. 28 (*a*). A view of the cross-section at *a b* is shown in (*b*). The forging is next trimmed while hot, using the trimming die shown in Fig. 29 (*a*), and the trimming punch shown in (*b*), after which it appears as shown in Fig. 30 (*a*). This completes the first operation, which is in fact the making of a complete forging, though not the one finally desired.

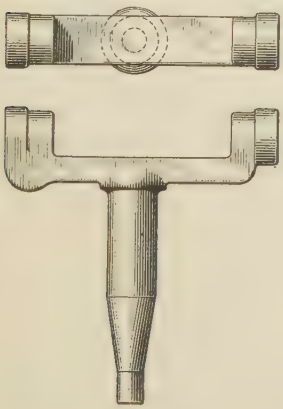


FIG. 26

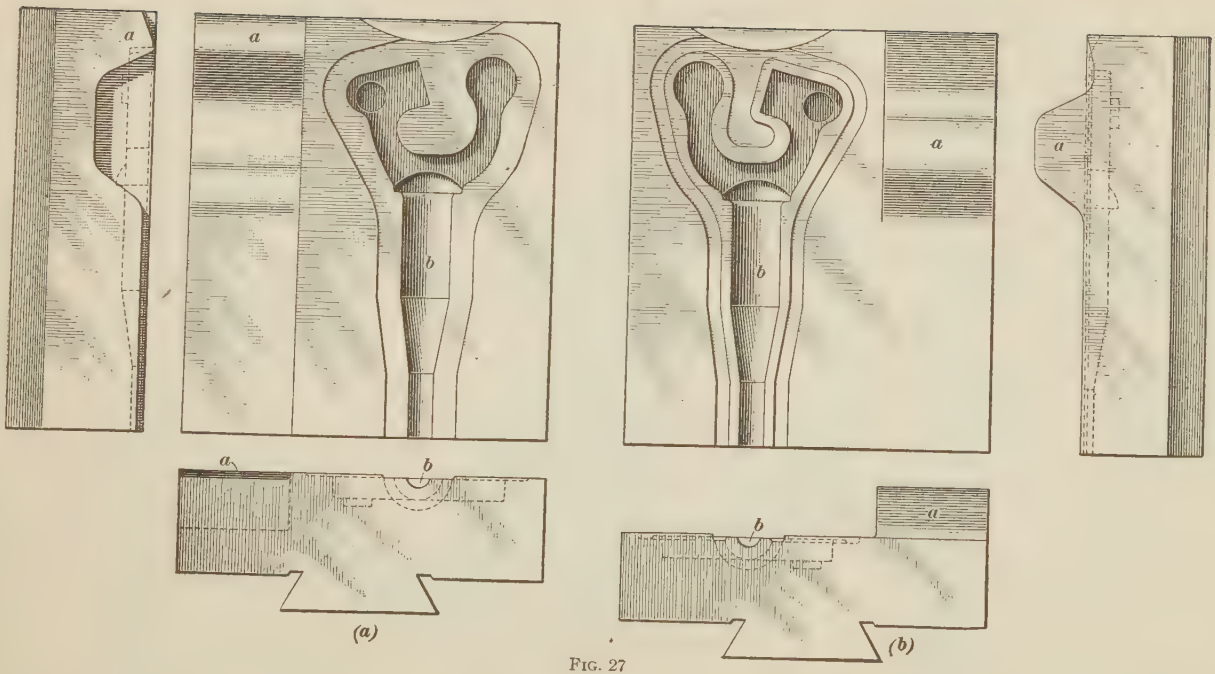


FIG. 27

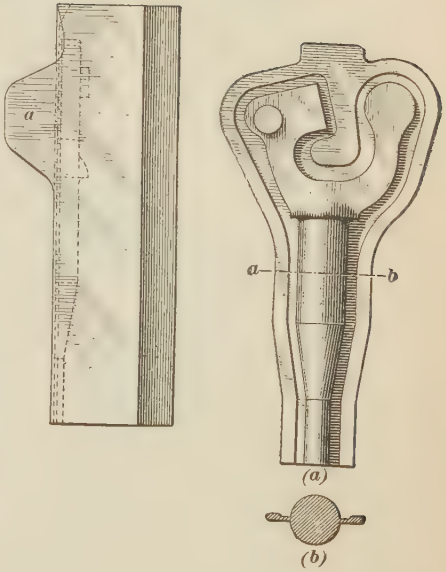
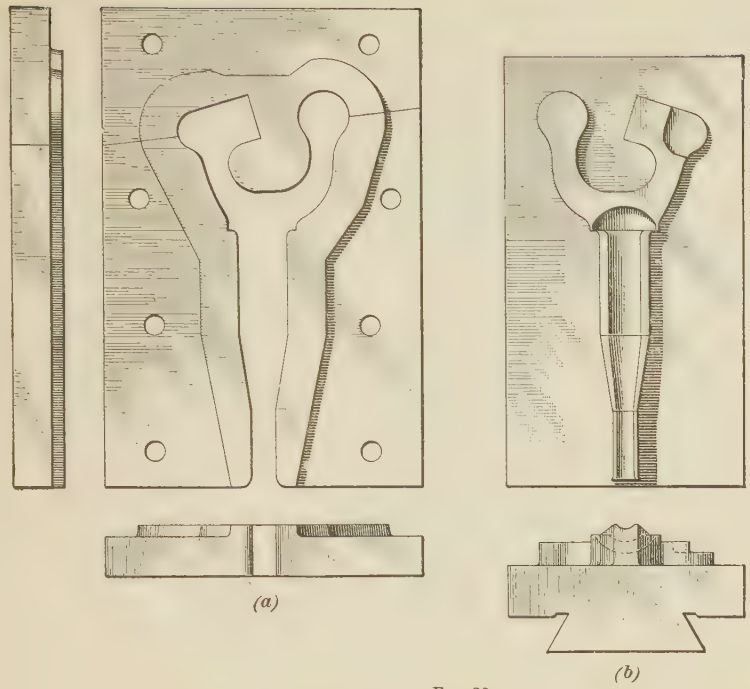
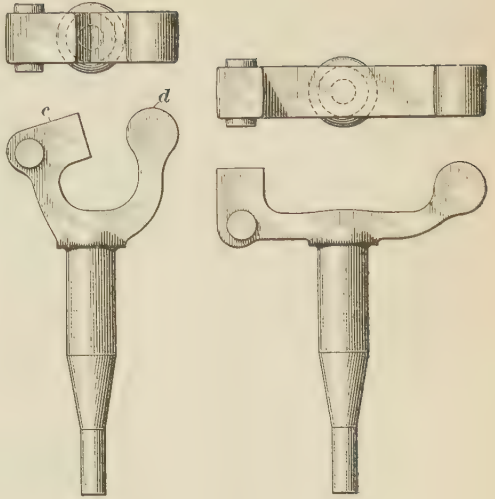


FIG. 28



(a) (b)

FIG. 29



(a) (b)

FIG. 30

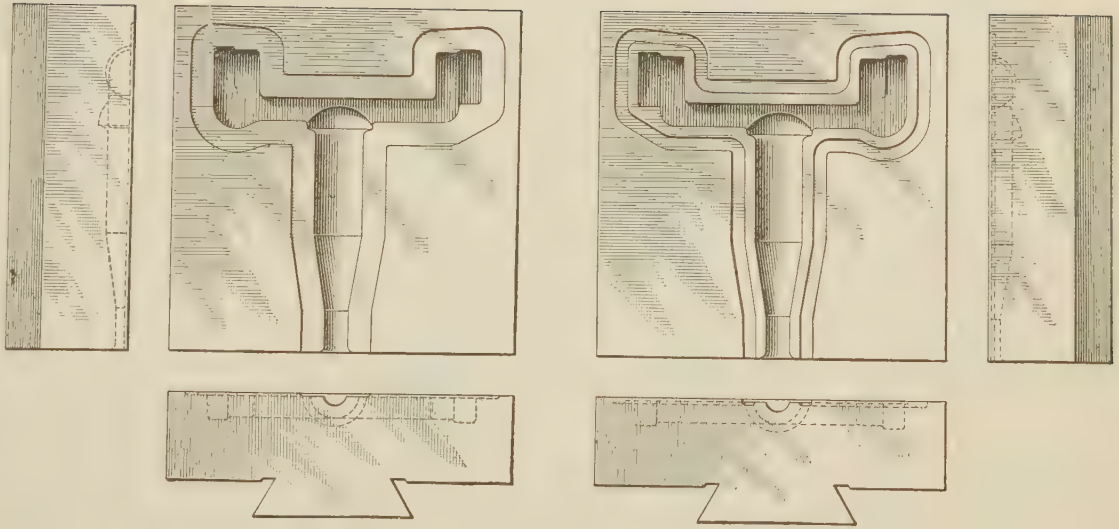


FIG. 31

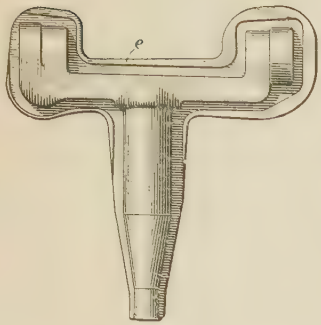
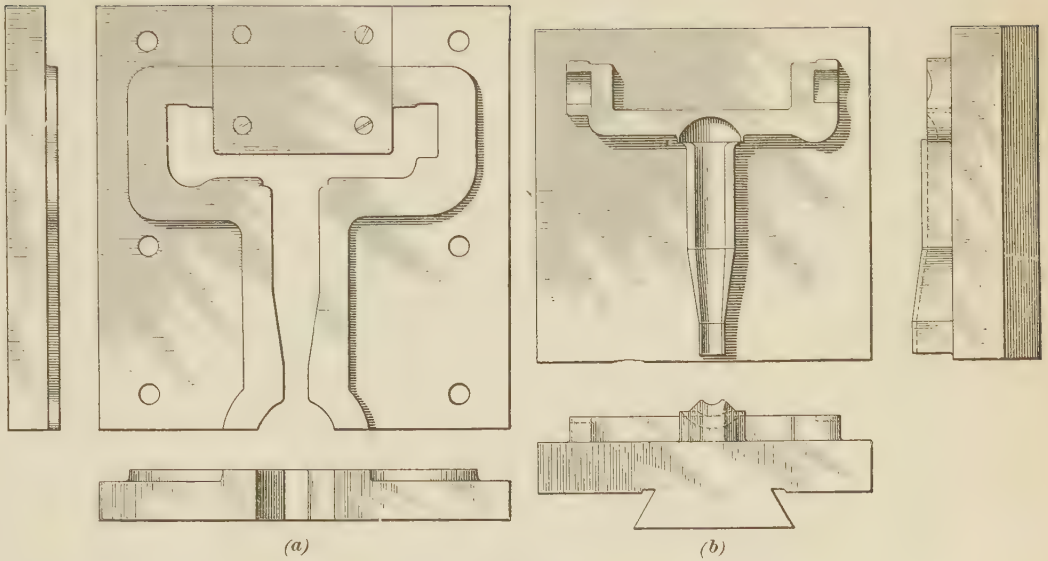


FIG. 32



(a) (b)

FIG. 33

The arms *c* and *d*, Fig. 30 (*a*), are next straightened out by the use of a hammer till the work appears as shown in (*b*), after which the work is forged to its finished dimensions in the

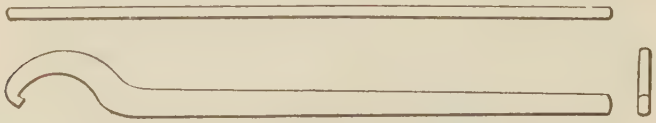


FIG. 34

dies shown in Fig. 31. In the figure, the bottom die is shown in (*a*) and the top die in (*b*). The forging now appears as shown in Fig. 32. The fin *e* is then removed by hot trimming, using the trimming die shown in Fig. 33 (*a*), and the trimming punch shown in (*b*). This completes the second operation, and the forging appears as shown in Fig. 26.

19. Dies for Long Spanner Wrench.—The drop forging of the long spanner wrench shown in Fig. 34 is another example of a two-operation job, although in this case the forging is finished in one pair of dies. This forging is made in two operations in order to reduce the size of the dies required to forge it, and to enable the work to be done on a much smaller hammer. The wrench is made by forging the large end first and it is then reversed and the other end is forged.

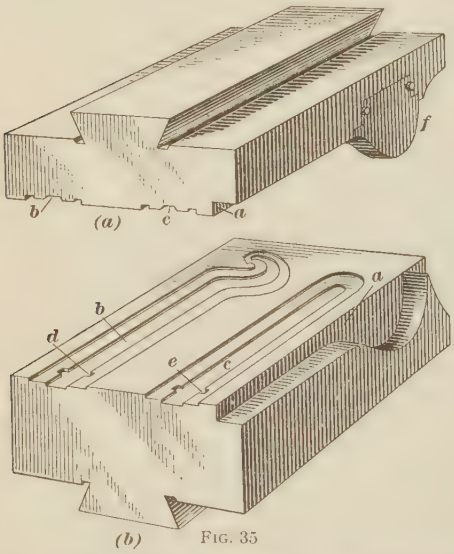


FIG. 35

The upper die is shown in Fig. 35 (*a*) and the lower die in (*b*). The breakdown is shown at *a*, which breaks down the stock that forms the large end of the wrench, no breakdown being required for the small end. At *b* is shown the forming impression for the

large end of the wrench, and at *c* the forming impression for the small end. The notches *d* and *e* serve as locating points and to prevent the metal from sliding forwards when struck. When

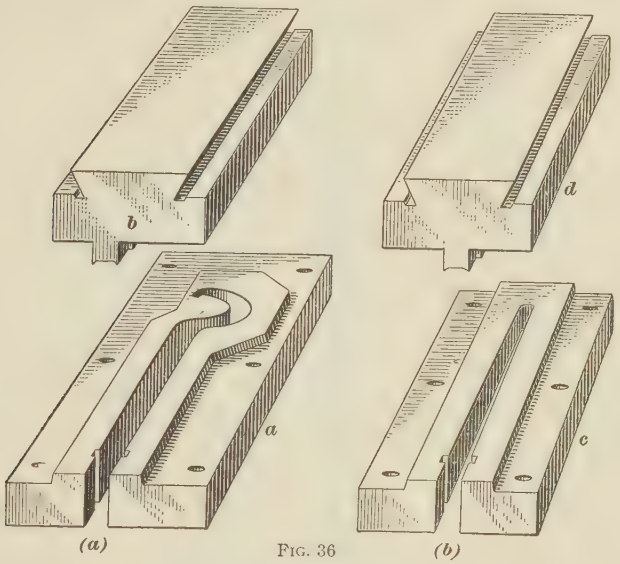


FIG. 36

the large end of the wrench is forged, lugs are formed on it by the notches *d*. These lugs fit into the notches *e* of the impression *c*, and thus locate the work in the forming impression for the small end. The part *f* in (*a*), known as the *horn*, or *bender*, is a separate piece that is dovetailed in place. The large end of the forging is trimmed by the use of the die *a*, shown in Fig. 36 (*a*), and the punch *b*; and the small end is trimmed by the use of the die *c*, shown in (*b*), and the punch *d*, the forging being hot trimmed. The small end is then moved backwards in the trimming die far enough so that the lugs formed on the sides may be removed with another stroke of the press. After trimming off these lugs, the wrench is struck again in the forging dies to round the edges where the lugs were sheared off.

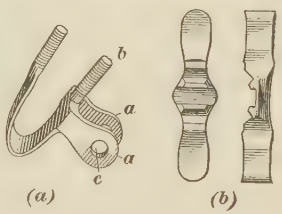


FIG. 37

20. Dies for Axle Clip.—The making of the axle clip shown in Fig. 37 (*a*) involves the following operations: Forging

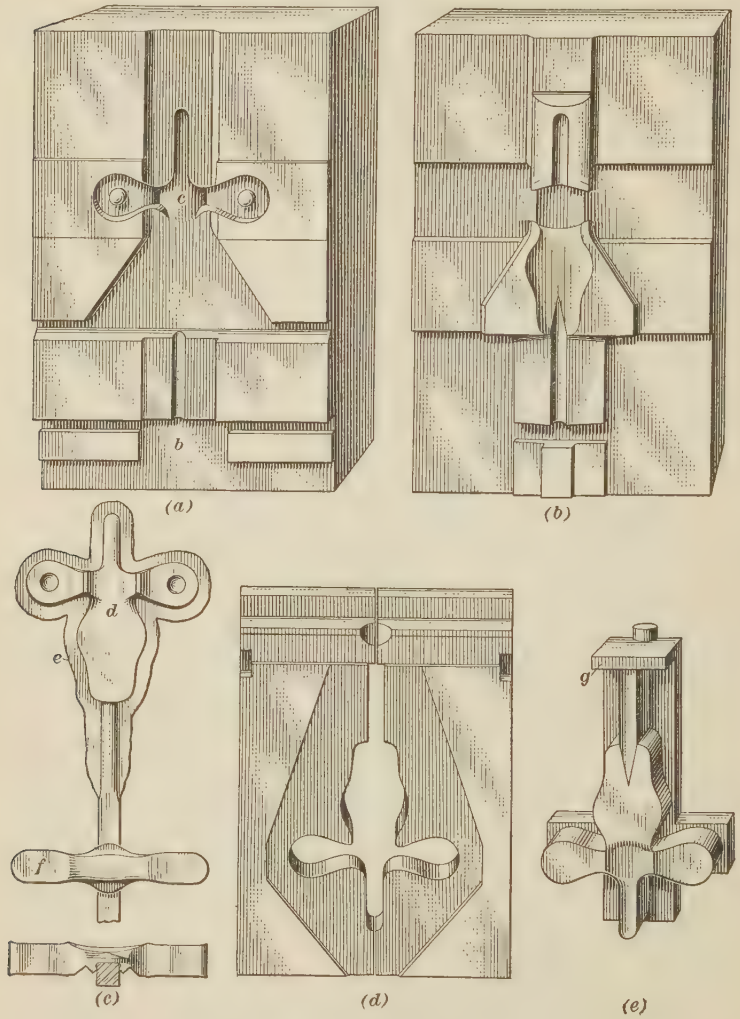


FIG. 38

and welding, hot trimming, hot bending, threading, cold bending, and punching. The part shown in (*b*) forms the lugs *a* of

the clip, shown in (*a*). These parts are made first by the use of a set of dies not shown. They are then welded to the stock forming the rest of the clip, after which they are drop forged. The welding and forging are done in the dies shown in Fig. 38 (*a*) and (*b*), the bottom die being shown in (*a*) and the upper die in (*b*). To make the weld, a part like that shown in Fig. 37 (*b*) is placed at *b*, Fig. 38 (*a*), the stock for the main part is laid on it, and the upper die is dropped, sticking the parts together. The work is now reheated, another piece like that shown in Fig. 37 (*b*) is put on the lower die at *b*, the heated part is then placed in the die with the part previously stuck to the bar in the recess *c*, and the upper die is again dropped, sticking the two parts together and at the same time forging and welding the clip. The work now appears as shown in (*c*), *d* being the forging, *e* the fin, and *f* the part stuck to the bar to become part of the next forging. The fin is next trimmed off while the work is still hot. The trimming die is shown in (*d*) and the punch in (*e*). When trimming, the work is supported on the die by the fin, and the punch, descending, forces the forging through the die. In Fig. 39 (*a*) the forging is shown as it now appears, and at *b* in (*b*) the fin is shown removed from the work. The cut-off *g* in Fig. 38 (*e*) also severs the fin *b* in Fig. 39 (*b*) from the stock *c*, as shown at *d*.

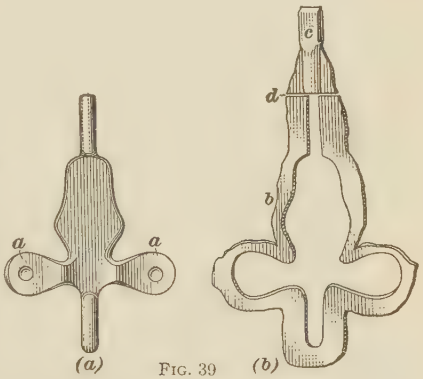


FIG. 39

21. After trimming, the forging is still hot. It is now picked up with a pair of tongs and placed on the bending die shown in Fig. 40 (*a*), secured to the bolster of an adjacent press, after which it is bent to the shape shown in (*b*) on the downward stroke of the punch, which is illustrated in (*c*). The forging is located on the die by the locating gauges *g* shown in (*a*), in which the lugs *a*, Fig. 39 (*a*), fit. The recesses *i*,

Fig. 40 (*c*), on the side of the punch, receive the lugs when bent, and the recess *j* receives the end *k* of the forging, shown in (*b*). After the forging has cooled, the ends *k* and *l* are threaded, and then bent to the form shown in Fig. 37 (*a*) by the die shown in Fig. 40 (*d*) and the punch shown in (*e*). To bend the forgings, each piece is in turn placed in the die, with the ends *k* and *l*, shown in (*b*), in the grooves *m* and *n* of (*d*), the lugs *o*, in (*b*), occupying the recess *p* in (*d*). The punch then descends

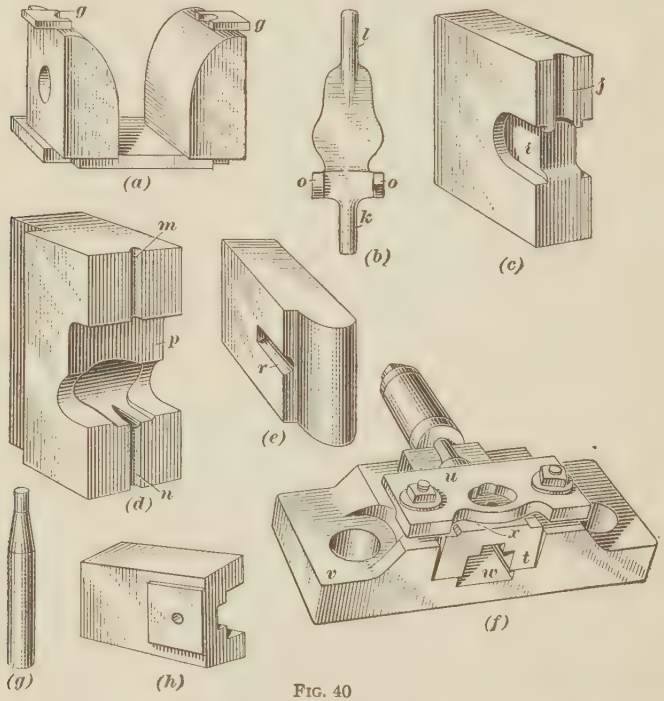


FIG. 40

and bends the forging to the desired shape, the end *b*, Fig. 37 (*a*), occupying the recess *r*, Fig. 40 (*e*). After the bending is completed, the holes *c*, Fig. 37 (*a*), are punched in the work, using the die and die holder shown in Fig. 40 (*f*), and the punch shown in (*g*). In (*f*), *t* is the die, *u* the gauge and stripper plate, and *v* the holder. The die *t* is shown removed in (*h*). To locate the work for punching, one of the lugs *a*, Fig. 37 (*a*),

is placed in the opening w, Fig. 40 (f), while the other is placed in the opening x and against a stop between the die t and stripper u. The punch on descending forces the punching down into the opening w. The work is then withdrawn and the other lug inserted in the opening x and punched.

The equipment needed to forge this piece is a furnace and hammer to make the part shown in Fig. 37 (b), and a furnace, hammer, press for trimming, and press for bending, conveniently arranged to bring the work to the form shown in Fig. 40 (b). A threading machine, press for bending, and press for punching are used to finish the work when cold.

HEADING AND BENDING DIES

HEADING-MACHINE DIES

22. Principle of the Heading Machine.—Heading machines are used principally to upset hot metal. To do this, the work is first gripped in a set of dies a, b, Fig. 41, that are recessed to the form of the forging desired. The machine is so constructed that one of the dies may be moved in the direction of one of the arrows c or d by operating a foot treadle; and when the dies are closed on the work, which is placed in the recess e, the work is held between them while the heading tool, or plunger, f moves forward in the direction of the arrow g and forces the hot metal into the recess in the dies. The plunger then moves backwards, the dies open, and the work is removed, after which the operation is repeated. As the forgings are usually made from bar stock, some provision must be made so that just enough stock will extend out in front of the dies to fill the recess when struck by the plunger. This length is generally determined by trial, and then a gauge, or back stop, h is set to

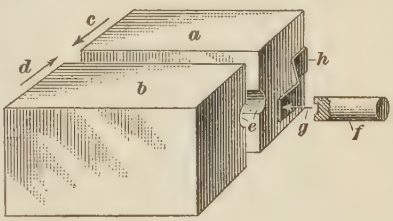


FIG. 41

the proper distance ahead of the dies. The bar is then placed against this gauge and is thus correctly located. The gauge is so controlled by the mechanism of the machine that it moves out of the way as the plunger moves forwards, and then automatically returns after the plunger moves back again. Ordinarily, one, two, or three grooves are made in the dies and one, two, or three heading tools are fitted into the machine at a time. In this way, two or three upsetting operations can be performed on a piece of work without changing the dies.

23. Heading Dies for Hexagon-Headed Bolt.—Suppose the hexagon-headed bolt shown in Fig. 42 (*a*) is to be forged in a heading machine. This can readily be done by the use of

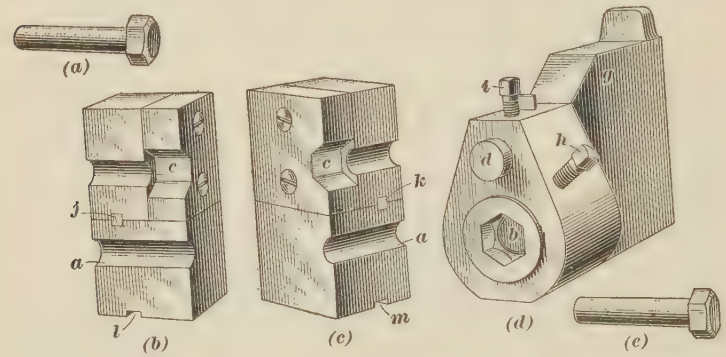


FIG. 42

the dies shown in (*b*) and (*c*) and the heading tool shown in (*d*). The stock is first located in the lower groove *a*, by the use of a gauge, not shown, after which it is upset by a blow with the heading tool *b*. It then appears as shown in (*c*). The next step is to place the head in the groove *c*, no gauge being required to locate the bolt at this setting, as the head already formed fits into the recess in the die. The work is finished by a blow with the heading tool *d*.

The heading tools *b* and *d* are held in place in the tool holder *g* by the setscrews *h* and *i*. In case the head need not be so well finished, the second operation will not be required and the head may be formed by the use of the lower groove *a* and the tool *b* only. The dies *a* and *c* are each made in two parts, and

are keyed together by the keys j and k. The bottom grooves l and m fit keys that are set in the machine, and by their use the dies are properly located relative to each other.

24. Dies for Bent Handles.—Work of the form shown in Fig. 43 (a) may be forged on a heading machine, the work being shaped by the set of dies shown in (b) and (c). The dies are shown in perspective in Fig. 44. In these illustrations the

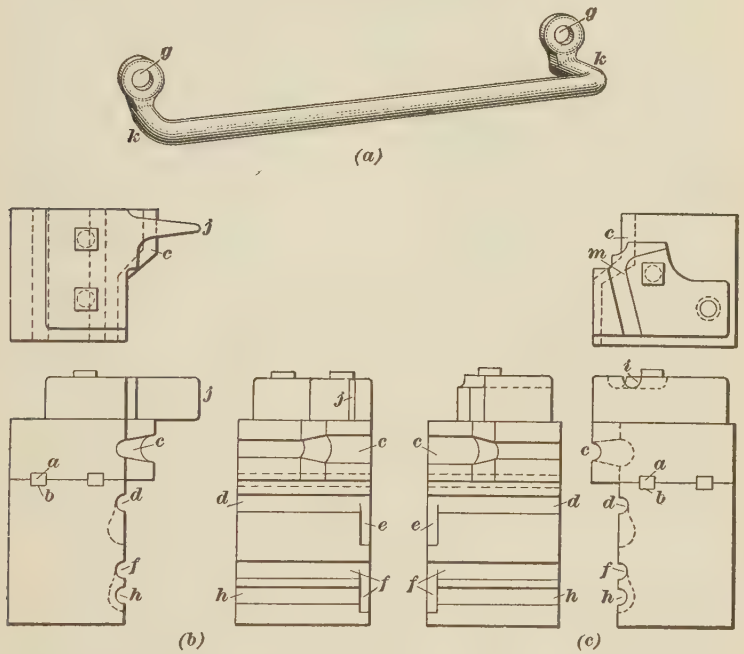


FIG. 43

same letters are used for corresponding parts. The upper and lower parts of the dies are located in the proper relation to each other by the keys a, that fit in the slots b. Each end of the handle is shaped in two heats. When heated first, the round stock is bent and upset in the upper groove c. A gauge, not shown, attached to the machine, determines the position of the stock in the die; the stock is then gripped by the dies, and the heading tool forces the heated metal into the depression in

the die. The stock is next reheated, and gripped in the depression *d* in the lower die, after which the plunger forces the metal into the opening *e*. The work is now placed in the depression *f* and a punch secured to the plunger punches the hole *g*, in the upset portion, and the punching passes out through *h*.

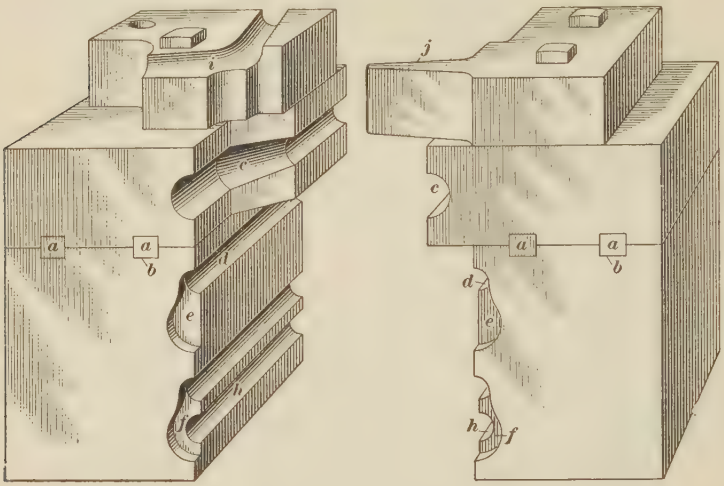


FIG. 44

Without reheating, the work is placed in the groove *i* on the top die, and the dies are again closed, the bending tool *j* forming the right-angled bend *k*.

BENDING DIES

25. Use of Bending Dies.—When it is necessary to bend heavy hot metal to various shapes, a form of horizontal press, known as the *bulldozer*, to which a set of bending dies has been attached, is used. In Fig. 45, one form of bulldozer is shown, the bending dies *a* and *b*, being shown set up. The connecting-rods *c*, which are driven by a system of gears and pulleys, drive the ram *d* to which the movable die *b* is secured. During the operation, the die *a* remains stationary, while the movable die *b* advances and bends the metal to the shape of the dies. The dies shown are made to form the piece of work shown at *f*. To bend the work, a straight bar of hot metal,

that has been cut to the required length, is laid on edge against the face of the stationary die *a*, the machine is then started, and the movable die *b* advances slowly, and bends the stock to the outline of the dies. The dies are almost always made of cast iron, and are usually made ribbed, instead of solid, in order to lighten them. As a rule, drawings of the dies are made in the drafting room, after which the dies are cast, and then planed to the required dimensions in the machine shop. For a large variety of work, however, no machining is necessary, as satisfactory work may be turned out by using the dies just as they come from the foundry. Dies of this class are used to bend a very large variety of work, as forgings for car trucks, agricultural implements, etc.

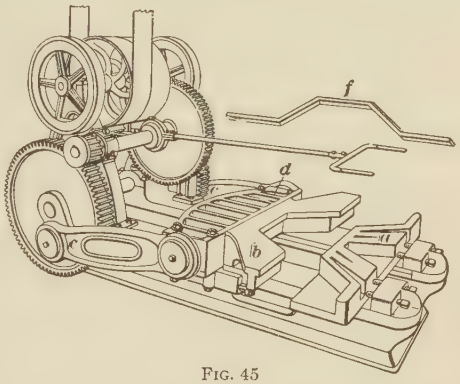


FIG. 45

26. Simple Bending Dies.—A simple form of bending die is shown in Fig. 46. Here the stationary die is shown at *a* and the movable die at *c*. They are so formed that when the movable die is forced against the blank strip of stock *b*, indicated by dotted lines, it will be bent to the required shape. In a bending die, some form of gauge or stop may be used in order to locate the blank properly; this must be made to suit the shape of the blank, and in its simplest form may be a shoulder, as shown at *d*.

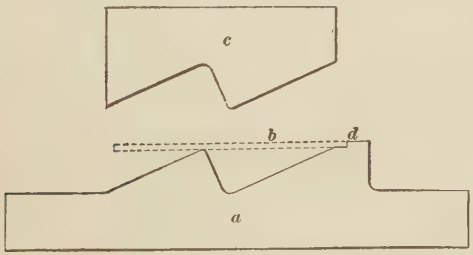


FIG. 46

27. Cold Bending.—When the piece that has been bent cold, as, for instance, that shown in Fig. 47, is examined, it will be found to have a shape slightly different from that of the die. Thus, if the dotted lines represent the shape of the piece while between the faces of the dies, on removal it will assume the shape shown in full lines, by reason of the elasticity of the material. Hence, it follows that for elastic materials the bending surfaces must be arranged to bend slightly beyond the required angle; how much beyond must be determined by experiment in each particular case. In general, the amount will be least for comparatively non-elastic materials, as annealed iron, copper, or brass, and most for more perfectly elastic metals, as spring steel, hard brass, etc. With metals like lead, or hot metals, no allowance need be made.

FIG. 47

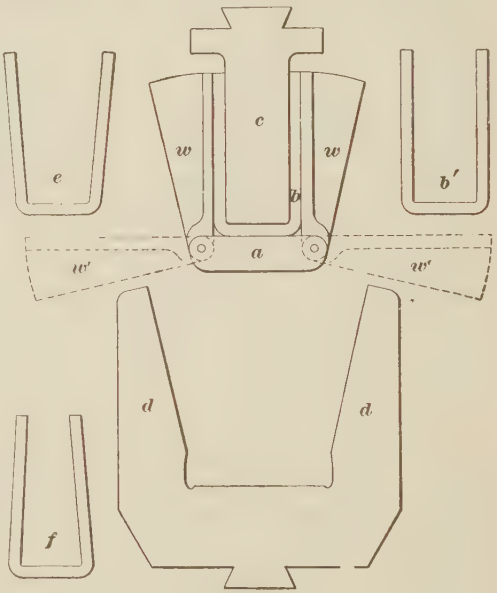


FIG. 48

28. Wing Dies. Fig. 48 shows a form of wing die that has hinged parts, or wings, w, and is well adapted for use in a bull-dozer. As the punch c advances, the wings w of the die a are folded in by the die d, thus bending the iron b without stretching it. The part d acts as a cam to close the wings of the die. The illustration shows a piece of stock b, with the wings w closed about it; the dotted lines at w' show the position of the

wings when the die is open. When the wings are open, the flat piece of stock is laid against them. When working cold metal, if the punch c is made with parallel sides, as in the figure, the work will not come out parallel, as at b and b', but will be somewhat divergent, as at e, on account of the elasticity of the metal. To overcome this, the punch must be made with its edges a little convergent, so that the work when closed will have somewhat the appearance of the piece shown at f. The subsequent expanding when released will restore it to a parallel form. The amount of this divergence depends on the kind of metal and the amount that it is heated. If entirely red hot when finished, it will act something like lead, which is practically non-elastic. As the metal is partly cooled when compressed between the cold or nearly cold dies, it may not have the exact form of the die when cold.

CONSTRUCTION OF FORGING DIES

MATERIALS AND EQUIPMENT

29. Materials.—In places where only a few forgings are produced, the dies are frequently made from a close-grained cast iron, the faces being cast to approximately the correct form and finished with a file or a scraper. Large forming dies have been cast so perfect that practically no finish was required. Cast-iron dies are sometimes made with chilled faces, to increase their hardness and wearing qualities. Ordinary dies for making large quantities of duplicate work are made from steel, both steel castings and well-annealed steel forgings being very largely used. In most cases these are cast or forged smooth on the face, and the desired forms are cut in them by milling, chipping, and scraping.

30. In cases where a very large amount of work is to be done, the dies may be made of about .60-carbon open-hearth steel, and one or both of the dies are then hardened by heating them to a cherry red heat and immersing them in a bath of

water or brine These dies must afterwards be tempered to make them less brittle and relieve the internal stresses. Dies for large forgings are often made of about .80-carbon steel, and left unhardened. This is done to reduce the danger of checking or cracking in hardening, the unhardened steel being hard enough to resist the tendency to stretch. Again, dies that have thin projections in the recesses are frequently made of about .80-carbon steel and not hardened; for if the die were hardened, the thin projections would likely break off. In case the dies are to be used to forge tool steel or other hard steel, a steel fairly high in carbon is generally used. When the material of the dies is too low in carbon, the force of the hammer blows it receives in service may cause the central part of the die face to sink below the level of the rest of the die. This is known as **dishing.** Dishing may be prevented by using a tool steel for the dies, and then hardening the dies to a sufficient depth to withstand the tendency to dish.

31. Die-Sinking Machine.—As die making is a branch of toolmaking, the equipment used for the one is, as might be expected, largely the same for the other. The machines most commonly used for die making are lathes, shapers, milling machines, drill presses, and die-sinking machines. In Fig. 49 one form of machine especially adapted to die sinking is shown. The machine is a form of vertical milling machine in which the work is held in the vise *a* that is attached to the table *b*. This table may be moved crosswise by means of the hand wheel *c*, and lengthwise by means of the hand wheel *d* or by operating the longitudinal power feed by means of the lever *e*. The cutting tool, which of course revolves, is held in one of the spindles *f* and *g*. The head *h* of the machine is moved up and down by means of the hand wheel *i*, and the spindles are driven by belt and gearing operating through the pulleys *j* and *k*, and the shaft *l*. The weight of the head *h* is balanced by means of weights that are attached to the chain *m*. The die block to be machined is secured in the vise *a*.

32. As a single spindle large enough to withstand heavy cuts cannot be provided with a sufficient range of speed to

suit the delicate cuts made with small cutters and the low speeds required for the large heavy cuts, two spindles *f* and *g* are

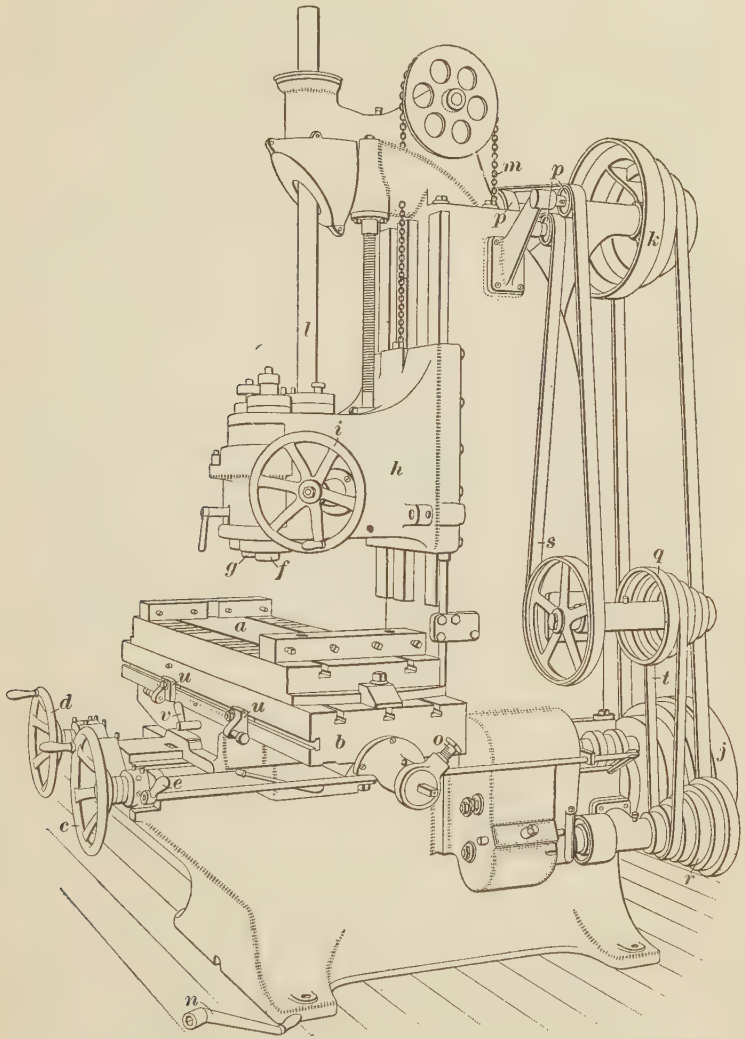


FIG. 49

provided, *f* being the larger and used for the heavy cutting. Either spindle may be used, as desired. A quick hand return

for the table is obtained by using the crank *n*, which fits the square on the end of the screw, and adjusting the lock bolt *o*. The feed is driven through the pulleys *p*, *q*, and *r* and the belts *s* and *t*. The pulley *j* is the main driving pulley, and is driven, in turn, by a countershaft connection or an electric motor, as found most convenient. The table stops *u* may be set as desired. As they pass the lever *v*, they automatically throw off the feed. The cutters used on the machine may have either tapered or straight shanks. Those having tapered shanks may fit directly in the spindles, or they may fit a socket that fits the spindle holes; and those having straight shanks are used in a chuck made for the purpose as, for example, the one shown

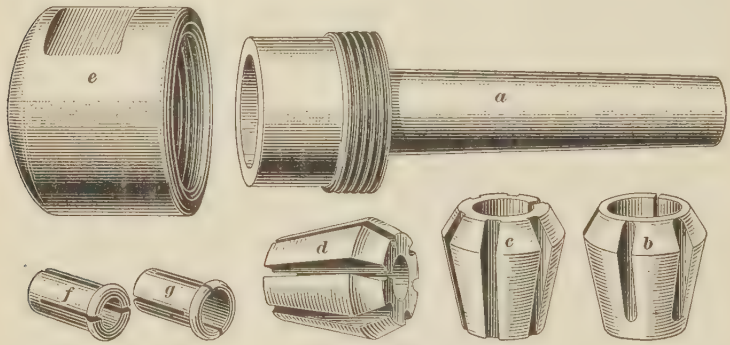


FIG. 50

in Fig. 50. The shank *a* of this chuck fits the spindle of the machine; the split bushings, *b*, *c*, and *d*, fit in the nut *e*, and the nut is then screwed onto the shank, clamping the bushings on the cutters. Bushings, *f* and *g*, of smaller size, may be made to fit into the larger bushings, in order to accomodate smaller tools.

33. Instead of the vise *a*, Fig. 49, a form of rotary vise, as the one shown in Fig. 51, may often be used to advantage on a die-sinking machine. By its use, short arcs may be cut much quicker than in any other way. To use this attachment, the table *a* of the machine and the vise *b* are set, by lining up the indicating marks placed upon them for the purpose, so that the center about which the vise rotates when in use will

be directly in line with the spindle of the machine. The indicating marks are not shown in the illustration. When the marks are once established, the machine may be readily set up for circular milling at any future time. After setting up the vise and table, a pointed center is placed in the chuck and the chuck is put in the spindle. The die block is next located and clamped in the vise so that the center point of the arc to be milled is directly under the pointed center in the chuck. The table may then be moved off center far enough so that the cutter will mill the impression desired when the vise is rotated by means of the hand wheel shown at *c*. The pointed center is now removed from the chuck, a cutter of the desired form is put in it, and the impression is milled to the desired depth.

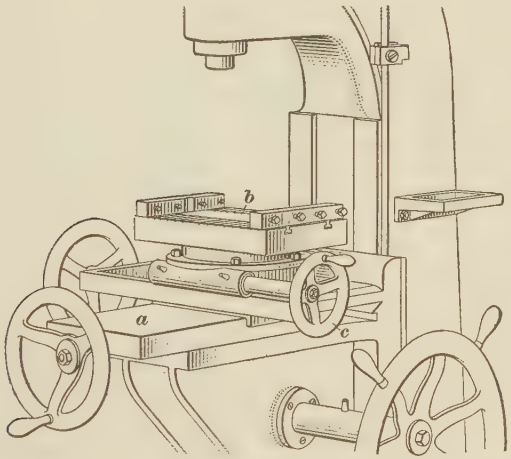


FIG. 51

34. Die-Sinking Tools and Cherries.—In Fig. 52 are shown a few of the large variety of cutters and long slender milling tools, called cherries, used in die making. Those shown at *a*, *b*, *c*, and *d* are made with tapered shanks to fit the tapered holes in the spindles of the machines, while the rest of the cutters shown are made with straight shanks and are held in a chuck similar to the one shown in Fig. 50. The tool shown at *e*, Fig. 52, is an ordinary pointed center that is made

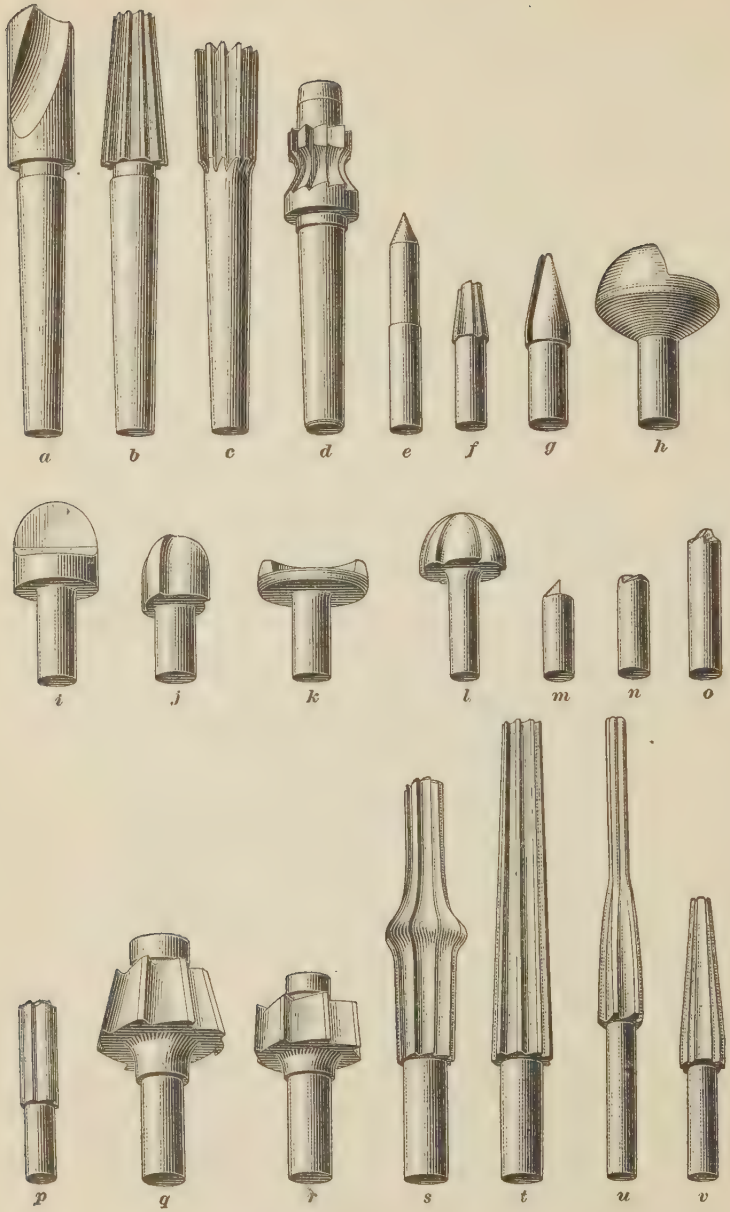


FIG. 52

to fit a chuck. It is used when it is desired to line up the spindle of the die-sinking machine with a point on the die block, as, for example, when setting up work in the circular vise. The tool shown at *a* is a roughing cutter, and, as its name implies, is used only to quickly remove large amounts of metal without regard to a fine finish. A 5° cutter is shown at *b*, a 7° cutter at *f*, a 10° cutter at *g*, and a trimming cutter at *c*. The 5°, 7°, and 10° cutters are used to finish the sides of the impressions, and when so used, a taper, or draft, of 5°, 7°, or 10° is provided, so that the forging can be easily removed from the dies. A large variety of special forming cutters are used in die sinking, a few of these being shown at *d*, *h*, *i*, *j*, *k*, and *l*. At *m*, a 45° cutter is shown, while the ones shown at *n* and *o* are special cutters. At *p*, *q*, *r*, *s*, *t*, *u*, and *v*, a few of the large number of different shapes of cherries are shown, these being of the average type. Cherries are made of almost any form to suit the impression to be made in the die block.

35. Cherrying Attachment.—A **cherry** is a milling cutter usually made together with its arbor as one piece, the length of the arbor varying with the requirements of the work to be done. Cherries are used, as a rule, on some form of universal milling machine or, in an attachment for the purpose, on a die-sinking machine. When one-half of an impression is cylindrical, cherries are used to mill out the stock, the shank of the cherry being made the same diameter as that of the sprue. The cherry is then sunk into the work until the shank comes in contact with the sprue. This operation is known as **cherrying.** In Fig. 53, a cherrying attachment *a* for the die-sinking machine is shown attached to the large spindle *b* of the die-sinking machine. It is clamped to the under side of the head *c*, and may be swiveled and securely clamped in different positions. The tapered hole *d* is the same as that of the spindle of the machine and, consequently, the same arbors that fit in the one may be used in the other. The purpose of the attachment is to bring the axis of the cutting tool horizontal instead of vertical, as this is the most convenient arrangement for cherrying.

36. Ball Vise, Hammer, and Templet Holder.—The recesses in the die blocks are usually finished by hand work, such as chipping, scraping, riffling, typing, and polishing. To facilitate this work, the die blocks are usually held in a ball vise, one form of which is shown in Fig. 54 (*a*). The die block is clamped in the space *a* by the setscrew *b*, and the part *c* of the vise rests on a pad of leather *d* which may be made by coiling up a short length of 2-inch belt and riveting it together at

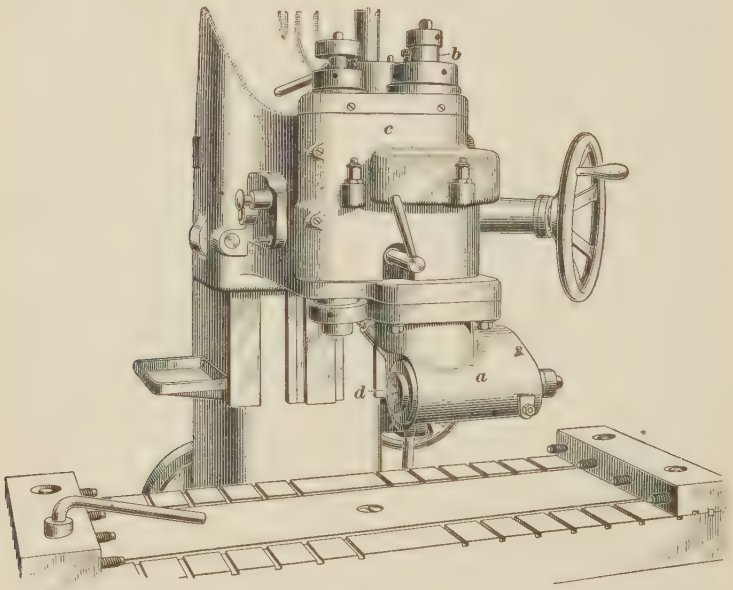


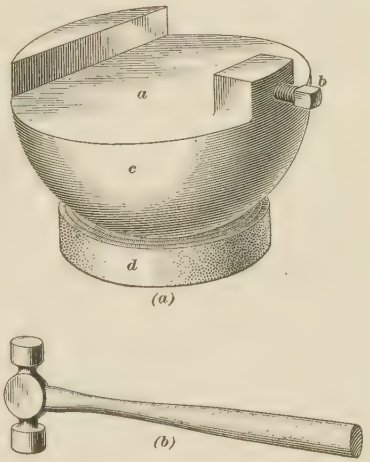
Fig. 53

intervals. By the use of this vise the work may be held at any desired angle, the weight of the work being sufficient to resist ordinary chipping.

The die maker generally uses a special hammer, shown in Fig. 54 (*b*), for chipping. It is made with two flat faces.

As the outline of the recess to be sunk in a die block is usually laid out on its face by the use of a templet, it is often found convenient to use a holder of some form to hold the templet firmly while scribing its outline on the block. One form of

templet holder is shown in Fig. 54 (*c*), in which *f* is the die block on which the templet is clamped at *g*. To use this holder, the legs *h* are first adjusted on the bar *i* to suit the work and then clamped in place by the thumbscrews *j*. The templet is then located on the block, and the holder is set in place, after which the thumbscrews *k* are tightened, and the templet is then forced firmly against the face of the block by adjusting the screws *l* and *m*. The screw *m* turns inside of *l*, this arrangement being used so that the screw *m* may be easily forced downwards without turning it.



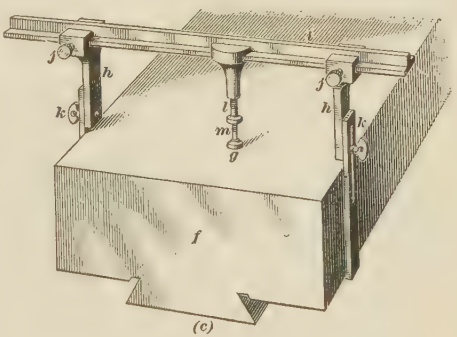
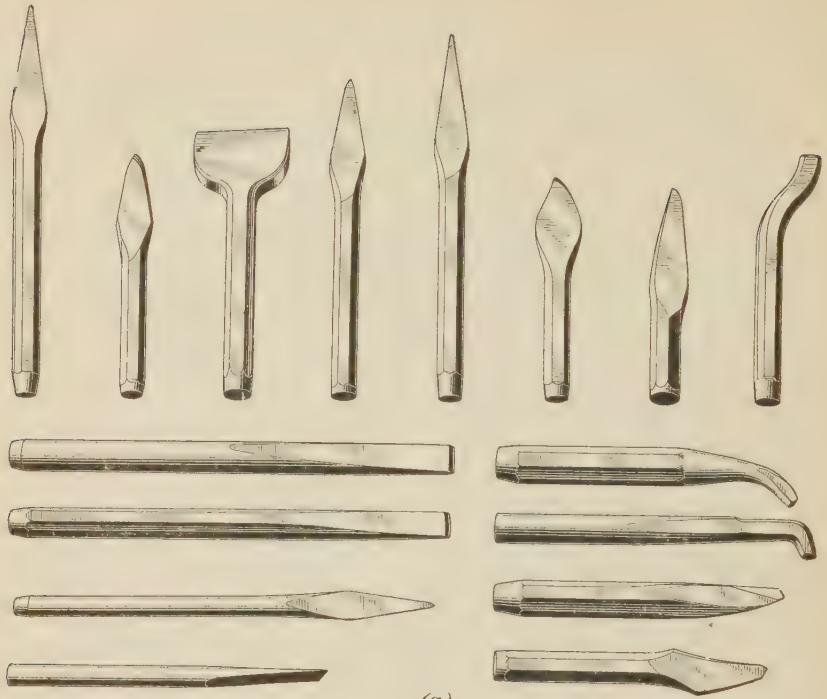


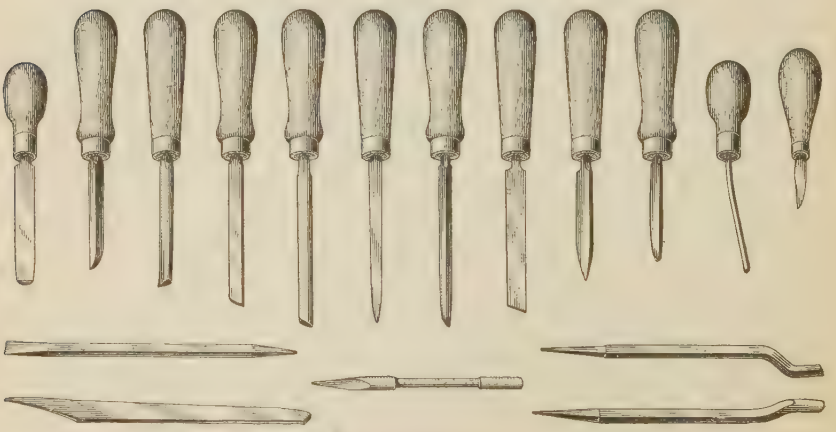
FIG. 54

37. Chisels and Scrapers.—Die maker's chisels are generally forged from hexagon or octagon tool steel to the shapes best suited to the work. Some of the common shapes are shown in Fig. 55 (*a*). The curved and flat shapes are used mostly, although a large variety of irregular shapes are also necessary. The flat chisels vary in width from $\frac{1}{32}$ to $\frac{1}{2}$ inch, and the curved chisels are made with many different curves.

After most of the steel has been removed by milling and chipping, scrapers are used. The scrapers may be of the ordinary three-cornered and half-round forms used by machinists



(a)



(b)

FIG. 55

and toolmakers generally, but, ordinarily, they are made of square and half-round stock in a variety of shapes, as shown in Fig. 55 (*b*). They are short, they cut on the ends only, and are made to fit in short round handles.

38. Rifflers.—After the scraping is finished, rifflers, or small bent files, are used to smooth the surface. In Fig. 56

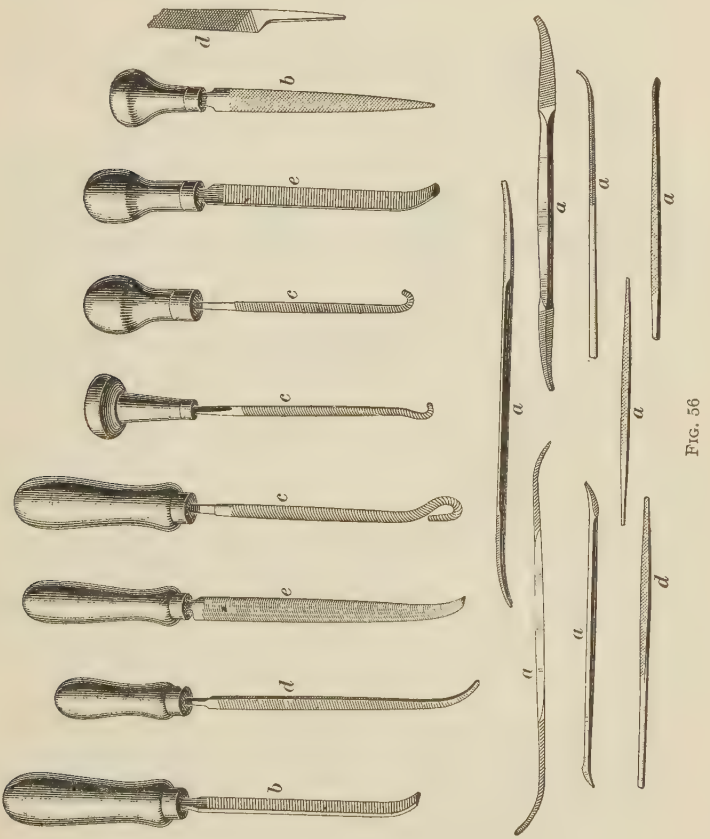


FIG. 56

a number of rifflers are shown. They are made in a large variety of shapes, sizes, and cuts. The operation of removing metal by the use of rifflers is known as **riffling.** The riffler is held lightly in the hand and is worked back and forth over the

surface to be smoothed. Spoon rifflers, shown at *a*, are spoon shaped and are made with many different curves. They are the most commonly used of all rifflers, as by turning them while riffling, different curved surfaces may be formed and most spots in the recess can be reached. Flat rifflers *b* are also largely used. They are made in many different shapes and widths. At *c* and *d* hook rifflers and knife rifflers, and at *e* half-round rifflers, are shown.

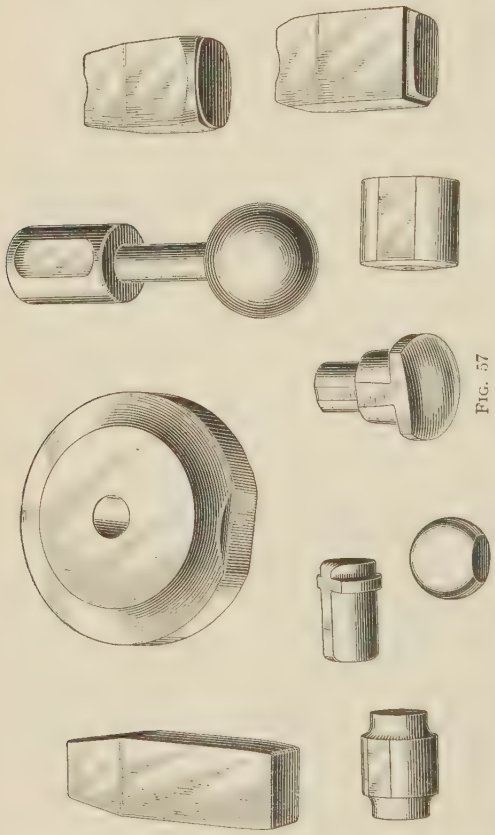


FIG. 57

39. Types. When the die recesses are deep and narrow, it is often difficult or impossible to chip, scrape, and riffle them to a finish. When this is the case, small blocks of steel, known as **types**, whose ends are shaped exactly like that part of the forging to be formed, are used. These types are turned, milled, and filed to shape and are then hardened and drawn to a purple color. A few forms of types are shown in Fig. 57. The operation of shaping a recess by the use of types is known as **typing**. Where types are to be used, the recess is first milled and chipped as near to the outline and depth as is safe, the type is then rubbed lightly with Prussian blue, or some other marking

material, then placed in the recess with a piece of copper or some other soft metal on top of it, and struck hard into the recess with a hammer. The marking material adheres to the high places in the recess. These high places are next chipped away and the operation of typing is repeated until the correct shape is obtained, after which the impression is finished by riffling.

DIE-MAKING OPERATIONS

40. Choice of Style of Die.—As a rule, the die maker is furnished with a drawing, a model of the finished part, or a sample of the forgings that the dies are to make. Then the die maker must know of what material the forging is to be made and the finishing operations through which the forging is to pass, in order that the correct allowances for shrinkage and finishing may be made. The form of the dies is then determined. First, the die maker must decide whether both a roughing and a finishing impression will be required and, if so, whether the finishing impression should be made in a separate set of die blocks. Other points then to be determined are whether a fuller should be used, the direction the impression should face in order that the best form of breakdown may be used, and the hammer in which the dies are to be used, in order that the dies may be made to fit that hammer. The die maker must also decide whether the forging is to be trimmed hot or cold. The determination of these points is largely a matter of judgment on his part. This judgment is based on his previous experience with dies made somewhat similar to the ones to be made, on the experience of others, and on his own original ideas.

41. Planing of Die Blocks.—The stock from which dies are made is generally obtained from the rolling mills in bars of the cross-sections desired, the bars usually being from 6 to 8 feet long. These bars are preferably prepared by planing first the top surface and then down the left-hand side, about 2 inches, after which the bar is turned over and the bottom is planed up forming a shank, or dovetail, of the proper bevel and height to fit the machines in which the dies are to be used.

From the bars thus prepared, blocks are then cut of any length needed, after which the front side is planed to a depth of about 2 inches, care being taken to have this surface square with the shank and the surface previously planed on the left-hand side of the block. Instead of planing the entire length of the bar at one setting, the bar may first be cut into the desired lengths and each block planed separately. The first method is, however, to be preferred, as in this way the blocks can be prepared much more cheaply. The object of planing the surfaces on the front and left side of the die block is twofold; first, to provide working surfaces from which to lay out the die recesses, and, second, to provide means to line up the dies in the hammer. It should be noticed that the left-hand, and not the right-hand, side of the die is planed. This is owing to the fact that the breakdown is always located on the right-hand side, and, consequently, this face would be destroyed when the breakdown is formed.

42. Allowances for Shrinkage.—As all metals expand when heated and contract when cooled, the recesses in the die block must be made larger than the size of the forging when cooled, to allow for this contraction or shrinkage. Shrinkage is most conveniently allowed for by the use of a shrink rule. When the forgings are to be cold trimmed, a shrinkage allowance of $\frac{3}{16}$ inch to the foot is made, and when they are to be hot trimmed, an allowance of $\frac{1}{8}$ inch to the foot is made. These allowances are the same, whether the forgings are to be made of wrought iron, steel, copper, or bronze. The difference in the allowances for hot and cold trimming is due to the fact that, when hot trimmed, the forgings are generally struck a finishing blow in the die after trimming, in order to straighten them. As the forgings are relatively cold at this time, the amount they will shrink will be less.

43. Allowances for Draft and Finish.—In case the sides of the die recesses were made vertical, the forging would stick in the die when struck. To prevent this, the sides of the recesses are made to slant away from the vertical a little and the allowance thus made is known as **draft.** The amount of

draft varies from 3° to 10°. For a thin forging 3° is plenty, for a deep die recess 7° is generally used, and for the central plug in a recess a draft of 10° is used, as in this case the metal will contract and grip the plug when cooling, and cause the forging to stick if the draft is insufficient. When the surfaces are curved or are at an angle with the vertical, no allowance is made for draft. A draft of 3° corresponds to a taper of $\frac{1}{16}$ inch to the inch; a draft of 5°, to a taper of $\frac{3}{32}$ inch to the inch; a draft of 7°, to a taper of $\frac{1}{8}$ inch to the inch; and a draft of 10°, to a taper of $\frac{3}{16}$ inch to the inch. The draft in the recess is usually cut on the die-sinking machine, using a 3°, 5°, 7°, or 10° cutter.

In case some parts of the forging are to be machined after forging, additional metal must be provided at those parts. This allowance is known as the **finish allowance.** It is usually about $\frac{1}{32}$ inch.

44. Laying Out of Dies.—In Fig. 58 (*a*) is shown the block for an upper die and in (*b*) that for a lower die. To lay out the dies, the faces *a* and *b* are first covered with copper sulphate, or blue vitrol, after which the center lines are scribed on both, being located from the working faces *c* and *d* in one case and *e* and *f* in the other. The outline of the recesses should be so located that the heaviest end of the forging will be at the front of the dies, as the forging will then be easier to handle while being worked and a good sized sprue may then be used. In case the outline of the forging is simple and regular at the joint line, the outline of the recesses may be laid out by the use of a square and dividers; but a thin sheet-metal templet of the forging is generally made for this purpose when the outline of the forging is irregular. The same templet will do to lay out both the lower and upper dies, and the trimming die and punch. Two or three combination squares may be used to locate the templet on the blocks in order that the outlines of the recesses on both blocks will line perfectly. The templet *g* is first placed in its proper position on one of the blocks, and is held there by a templet holder while the outline is scribed on the block. Combination squares *h* and *i* are then set from each of the

working faces of the block to the edge of the templet, after which the templet holder is removed. The templet is then placed, reversed, on the other block and located properly by the use of the settings obtained on the combination squares, after which it is clamped in place by the templet holder. The squares are then removed, and the outline is scribed on the die block.

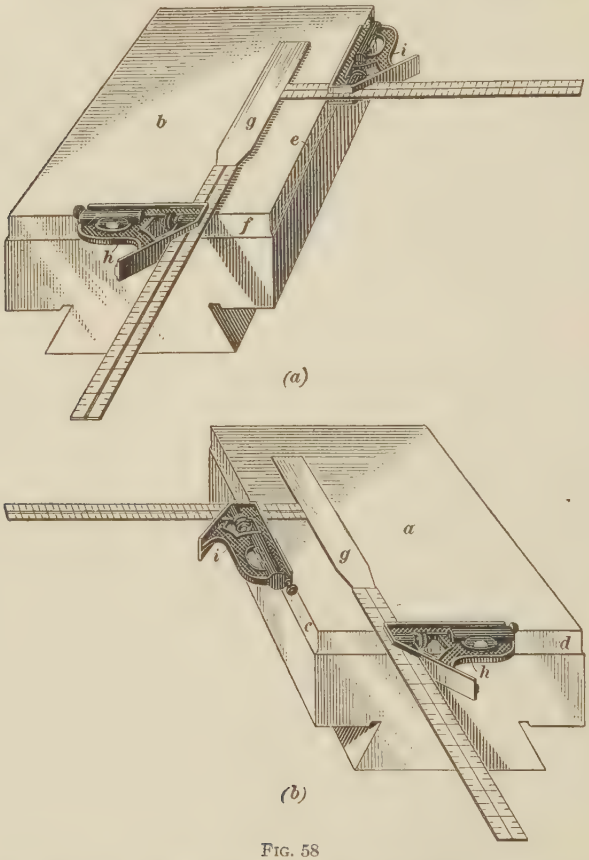


FIG. 58

The outlines on both blocks are then marked at intervals by prick-punch marks so that they will not be destroyed. The layout is completed by scribing lines for the flash, back flash, gates, and sprues, and then prick-punching them as before.

45. Machining of Die Recesses.—The recesses in the die blocks are shaped mainly by means of the die-sinking machine, although other machines are frequently used. Parts of the recesses may be formed by turning on a lathe. The milling machine, drilling machine, planer, and shaper are also quite often used.

46. The outlines scribed on the face of the block are used as guides when cutting the recesses. After the outside of the block has been finished and the parts that can be done on the lathe have been turned, the die is set up on the die-sinking machine, and the recesses are roughly cut to the lines laid out on the face of the block. After the impressions are roughed out nearly to size on the machines, they are finished by hand work. An example of a die block set up on a die-sinking machine for the milling of a gate is illustrated in Fig. 59. The die block is shown at *a*, and at *b* is shown a cutter of the form illustrated at *l*, Fig. 52, which is used for this operation. As a rule, when milling the recesses, oil is needed only when special forming cutters are used, and in that case lard oil is advisable. At *c*, Fig. 59, is shown a brush that is kept available to brush the chips out of the recess, and at *d* a small tube is shown fitted into a wooden holder *e*. This tube is used to blow the chips out of the recesses. The electric lights shown at *f* may be brought close to the work, when necessary.

The machine here shown differs from the one shown in Fig. 49, in that the vertical movement is obtained by raising and lowering the table of the machine instead of the cutter head. In either case, the raising or lowering of the table is accomplished by means of a hand wheel having a graduated dial that shows the motion of the table or head in thousandths of an inch.

47. Other parts of the die may have to be machined by means of the cherrying attachment on the die-sinking machine, or on the milling machine. The proper cherry is placed in the spindle of the machine, and the cherrying is done at this time. When machining the recesses, care should be taken to leave as little stock as possible to be removed by hand, as the hand work is much slower. For the last cut, the cutter should be

brought as close as possible to the finished form of the die. When the cutter is finally set for the last time, it should be run over the work two or three times in order to get the smoothest surface possible. The final cut should just split the lines scribed on the face of the die.

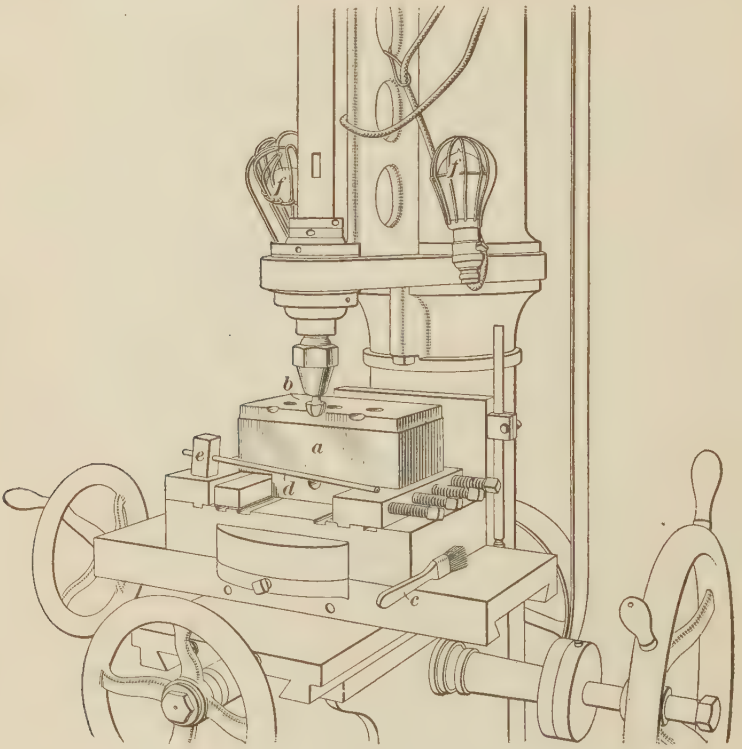


FIG. 59

48. Hand Finishing of Die Recesses.—After all the machine work is done, the corners and irregular parts of the recesses will still be unfinished. These are then chipped, scraped, riffled, typed, and polished, the die being held in the ball vise while doing the hand work. When chipping, it is advisable to chip down or away from the outline of the recess to avoid breaking out parts at the end of the cuts. Oil should be used sparingly and light cuts should be taken. Care

should be taken to try the templets and depth gauges often in order not to take out too much stock.

By the use of the scraper, the high points left by the chipping operation are reduced and the surface of the recess is made smooth. The die is finished to its correct dimensions with the scrapers, after which the surface is smoothed further by the use of rifflers. The rifflers and scrapers must be worked over the surface in different directions to prevent the formation of grooves and ridges. In Fig. 60 is shown the operation of scraping out a recess in the die block *a*, which is held in the ball

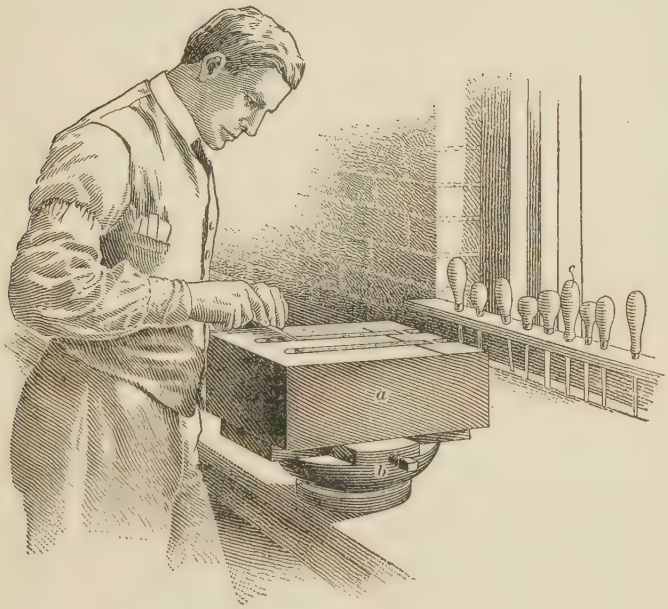


FIG. 60

vise *b*. The scrapers are shown at *c*. They are held in a rack located conveniently so that any of them may be had at once when needed.

A very smooth surface is required in the recesses of the die so that the forging will have smooth surfaces and come from the die easily. Every part must be carefully finished. This is done by use of coarse emery cloth first, and then fine, wrapped

around a file or a piece of wood. To polish the corners that cannot be reached by the emery cloth, emery and oil are used on the end of a small piece of wood, the emery embedding itself in the wood.

49. Lettering of Die Recesses.—When lettering is required on the forging, the dies are stamped in the bottom of the recess with a deep flat-faced letter that will give body to the letters on the forging. If the letters are very large, the recesses are chipped or milled out after lightly stamping the letters in the die to locate them. They are then readily stamped in the die to their full depth without removing much of the steel. To locate the letters in the recess, the central letter, or figure, is first stamped, and from this central letter the other parts of the word, or figures, are added.

50. Lead Proofs of Die Recesses.—After the dies are completed, a lead proof is usually made in order to check up the dimensions and to see if there are any defective places in the dies. To make the lead proof, the dies are cleaned, dusted with powdered chalk, set on their ends with the die faces together and with the working faces in line, and then securely clamped with a large **C** clamp. The lead is then melted and poured slowly and evenly into the dies. After the lead has cooled, the dies are unclamped and the lead is removed and examined. If the lead shows any changes in the recesses to be necessary they are then made, and another proof is made to be sure that the dies are correct. As the shrinkage of lead is about the same as that of steel, the finished forging will measure nearly the same as the lead proof. In the case of forgings made with holes in them, as, for example, any form of ring, the shrinkage allowance will have to be made when checking up the proof, owing to the fact that the hole in the forging is formed by a plug in the die recess, and this plug prevents the lead from shrinking when cooling. In the case of the forging, however, the shrinkage will take place, since it is not in the die while cooling. The finished forging will weigh about two-thirds as much as the lead proof; thus the weight of metal needed for the forging is readily determined.

51. Die Breakdowns.—The breakdown is not made in the dies until the face recesses, the flashes, gates, and sprues are finished. Then the dies are clamped together just as they were to make the lead proof, and the rough surfaces of the right-hand sides of the die blocks are chalked. The half of a lead proof or a templet of the forging is now laid on the side of the dies and the outline of the forging is scribed on them. If this proof or templet is symmetrical as it lies on the side of the dies, one-half of the outline should be located on each die; in other respects, the position of the proof or templet is determined by the experience of the die maker. The outline of the templet is then scribed on the dies. Another line $\frac{1}{16}$ inch inside of this line is scribed in all places. This is the working line of the breakdown. The dimensions of the breakdown are made smaller than those of the forging so that the broken-down stock will readily lie in the forming impressions. All the corners of the breakdown should be well rounded to avoid cold shuts when forging, and all the vertical parts are given a draft of 7°. The breakdown is made enough wider than the forging so that there will be plenty of room for the work; and it is made with a gate and sprue. A cut-off is formed at its rear end to trim off the extra stock drawn out under the fuller. After the correct outline is determined, it is prick-punched to make it permanent, and the die is then set up on the die-sinking machine, being set on its side in the vise. Then, using a long straight cutter, the breakdown recess is milled to the outline.

52. Hardening and Tempering of Dies.—After the breakdown is finished, the dies are ready to be hardened and tempered. If the dies are made of steel containing less than .60 carbon, it will be necessary to first carbonize their surfaces by packing them in a box of granulated raw bone, or other carbonizing material, and heating as explained in *Hardening and Tempering*. Dies made of steel containing more than .60 carbon need not be carbonized before hardening, and dies made of steel containing over .80 carbon are generally not hardened. To harden the dies, about 2 inches of burnt granulated raw bone may be placed in cast-iron boxes having walls

about $\frac{1}{2}$-inch thick, cast iron being used because it stands the heat well. The dies are then placed face down on the bone and settled down so that the bone fills the recesses. Burnt bone is used to prevent decarbonization of the steel and the formation of scale. The box containing the dies is then placed in a furnace and maintained at a temperature of from 1,425° F. to 1,450° F. for from 6 to 8 hours, according to the size of the blocks.

53. When properly heated, the dies are quenched in a tank in which the water supply discharges upwards, as shown in *Hardening and Tempering*, and having two bars suspended across its top to support the die. The water is turned on full force, as soon as the die is properly placed, and strikes against the die faces, thus preventing the formation of steam pockets. Where the dies are cold enough so that water will cling to their top corners, they are placed in an oil quenching tank till cold. The temper is drawn in oil, brought to a temperature of about 450° F. and kept at that temperature till the heat penetrates the dies. After the dies are removed from the oil, the corners of the recesses and the cut-off are drawn to about a purple color, using a blow torch. When cold, the recesses are polished, using emery and oil on the end of a stick, and the dies are then ready for use.

54. Trimming Dies.—The work of cold-trimming dies is a great deal harder than that of hot-trimming dies and they are usually made of high-carbon steel and hardened. Both the die and punch are made in the same manner as the ordinary blanking die and punch. A special grade of steel known as *hot-trimming die stock* is used for dies intended to trim the forgings while still hot. Ordinary tool steel is not suitable for this purpose because the edges of a hardened die crack badly after being in use a short time. The special grade of steel for hot-trimming dies does not require hardening and the dies made of it become tougher in use, and give very good service. The hot-trimming dies are made in the same manner as are the cold-trimming dies, the main difference in them being that the hot-trimming dies are left open at the front to clear the sprue that connects the forging to the bar. Either type of die may be made solid or in sections, as found most convenient.

SPECIAL FORGING OPERATIONS

SPECIAL FORGING EQUIPMENT

HEATING FURNACES

1. As heating is necessary in all forging work, suitable furnaces must be provided in connection with forging operations. The form of the furnace varies with the nature, size, and quantity of work to be heated, and with the nature of the fuel used; in many cases, one form can be used for several classes of work, but in other cases each class of work requires its own special form of furnace. Gas-fired or oil-fired furnaces are now preferred to those fired with coal or coke, because they can easily be controlled so as to maintain a more uniform heat. In all heating furnaces, the air supply should be so regulated as to produce incomplete combustion in the part of the furnace where the heating is done; in other words, there must be no excess of air, as such excess will oxidize the metal. In the case of heating furnaces using solid fuel, it is necessary to provide for the admission of air beyond the heating chamber, so as to burn the gases completely, if it is desired to prevent the escape of smoke from the chimney.

2. Small Coke Furnace.—For heating the ends of bars to be worked under drop hammers or in forging machines, a small coke furnace, like that shown in Fig. 1, is frequently used. This furnace is enclosed in cast-iron plates, the front and back plates *a* and *b* being bolted to flanges on the side plates *c* and *d*. The grate bars *e* are supported on bearing bars placed in the furnace lining, which is made of firebrick. The

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ashes are removed from the ash-pit through the door *f*. The blast pipe is generally inserted into the ash-pit through an opening in the plate *b*, and a pressure of from 4 to 12 ounces is maintained in the pit. A bed of coke is kept on the grate bars and the material to be heated is placed on the coke. The opening *g* through which the work is placed in the furnace is usually closed, or partly closed, by a firebrick-lined door, sliding between the vertical guides shown at the right and left of the door. The gases escape through a flue connected with an opening in the plate *b*. While the work is being heated, the

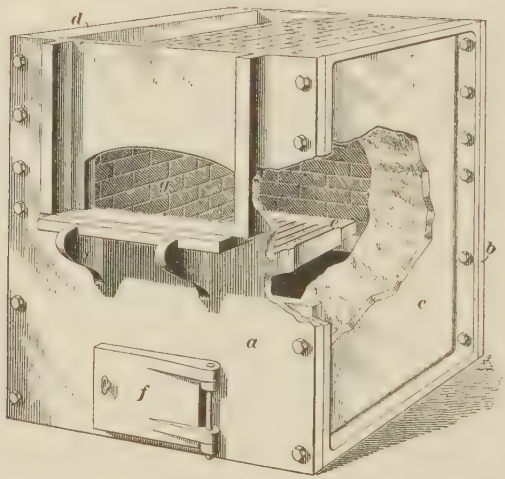

FIG. 1

door is kept closed as much as possible, to prevent any inrush of cold air over the top of the fire. The door is also usually provided with a counterbalance so that it can be raised or lowered with ease.

3. Reverberatory Furnace.—For heating large work, a reverberatory furnace is usually employed. The work is placed on the hearth and heated by the hot gases passing over it, and the heat reflected from the roof, which is a firebrick arch. In some cases, the roof is arched in such a way as to focus the heat on some part of the hearth. In a reverberatory furnace,

it is necessary to construct the lining of the furnace of firebrick laid in fireclay. A furnace of this type may use coal, oil, or gas, and for some classes of work wood; but good bituminous coal is the fuel most commonly employed. The fuel is usually burned with forced draft, the bed being kept deep enough to insure a slightly smoky flame, which indicates incomplete combustion. This makes it certain that oxidation will not take place from air passing through the grate.

4. A longitudinal section of a furnace used in heating work for a steam hammer is shown in Fig. 2. The coal is thrown on the grate *g* through the fire-door opening *h*, which is so placed

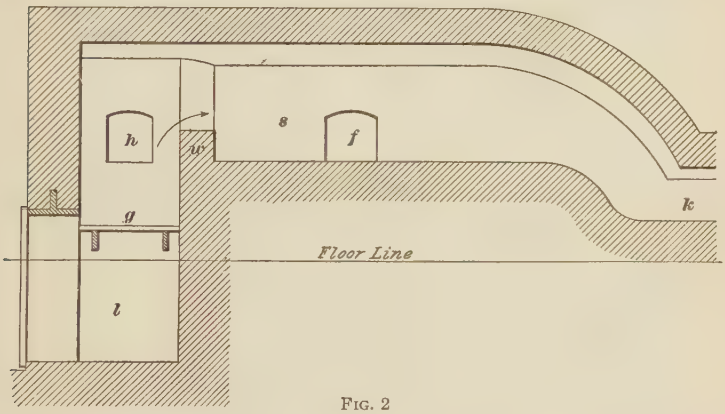

FIG. 2

that a suitable depth of fire can be maintained between the grate bars and the bottom of the door. The hot gases pass over the bridge wall *w*, and burn in the chamber *s*, the waste gases escaping through the flue *k* into the stack. The ash-pit is shown at *l*. A plan view of the furnace is shown in Fig. 3, a side view in Fig. 4, and an end view in Fig. 5 (*a*), while (*b*) shows a section crosswise through the hearth. Corresponding parts in these different views are given the same reference letter. The furnace has three doors *c*, *d*, and *e* on one side, and the door *f* and the fire-door *h* on the other, the door *f* being opposite the door *d*. This is a great convenience in heating long pieces of work, which are allowed to extend through both openings. All the openings

through which work is put into the furnace are closed by doors lined with firebrick slabs and suspended by chains from counter-

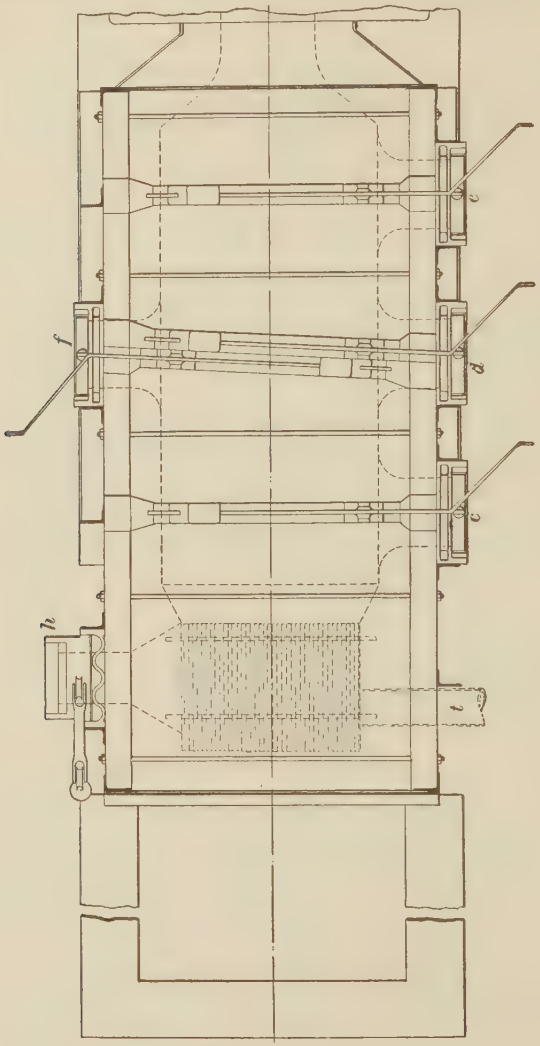

FIG. 3

balanced levers. They are raised and lowered by the handles *p*, and the weights *n* serve to hold them in any desired position.

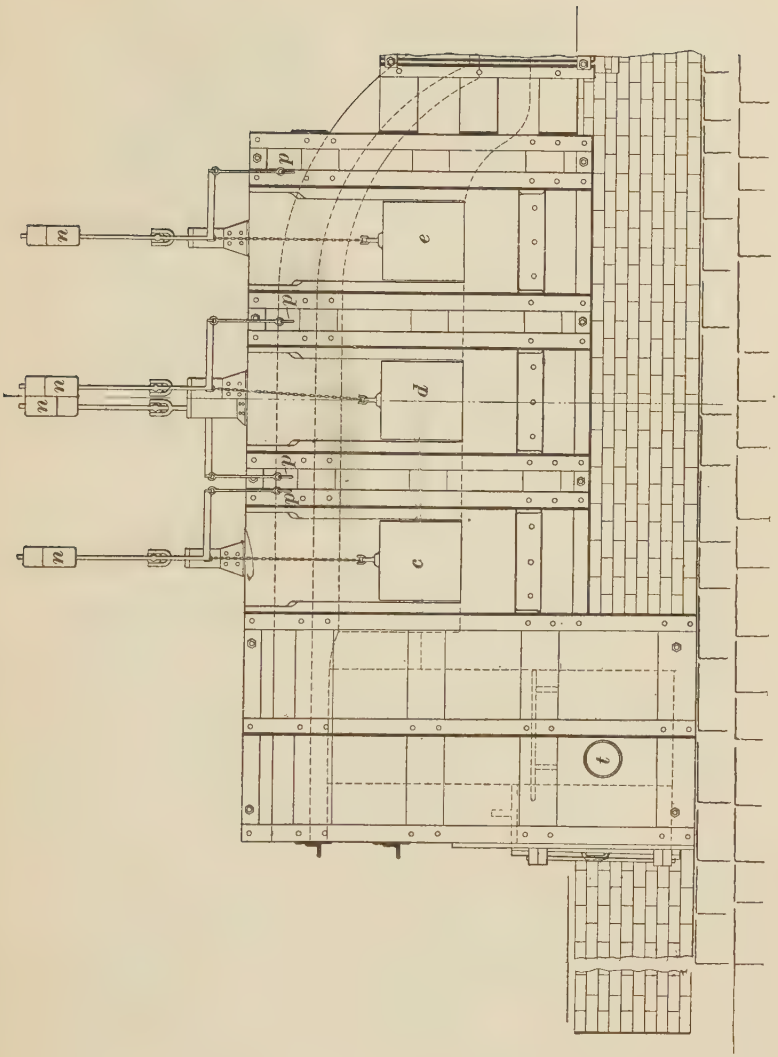

FIG. 4

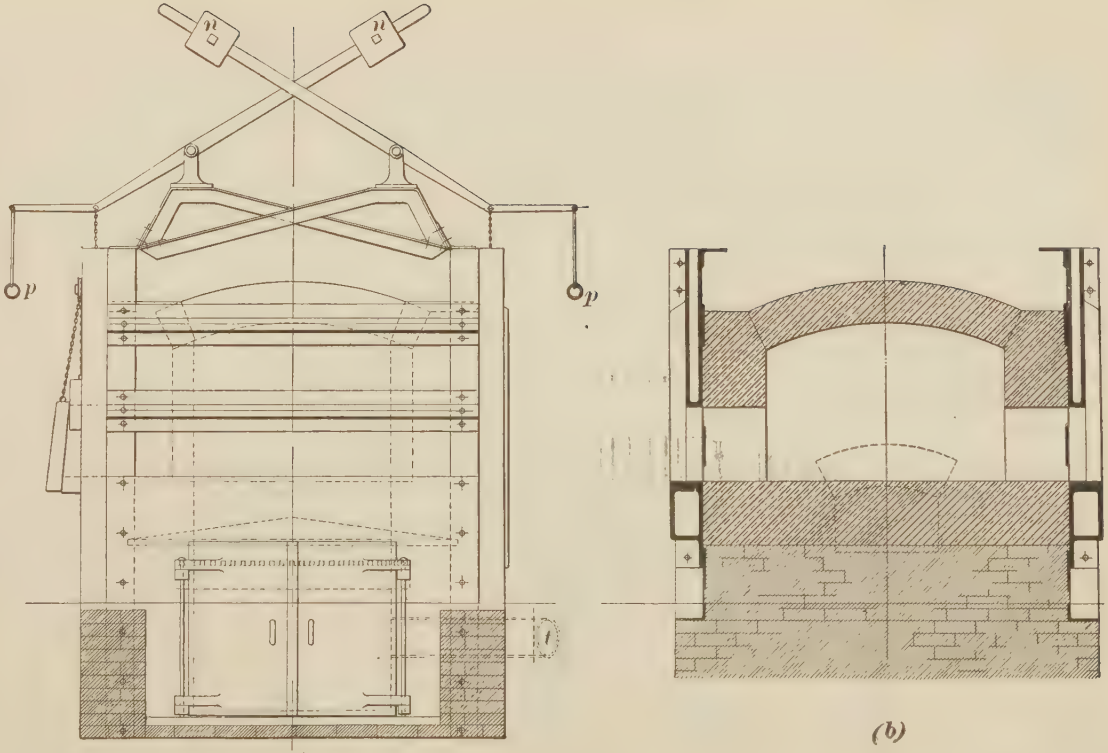

FIG. 5

5. The bed, or hearth, of the furnace is usually made of clean, sharp silica sand tightly rammed to nearly the shape of the hearth. A fire is then placed on the grate and kept burning until the sand on the surface melts and forms a smooth glassy hearth. Sometimes clay is mixed with the sand.

In heating work, sand is very frequently used as a flux to carry off any iron oxide that is formed on the surface of the metal. Iron oxide also attacks the surface of the hearth, forming a fusible slag with it. This slag flows into the slag pot

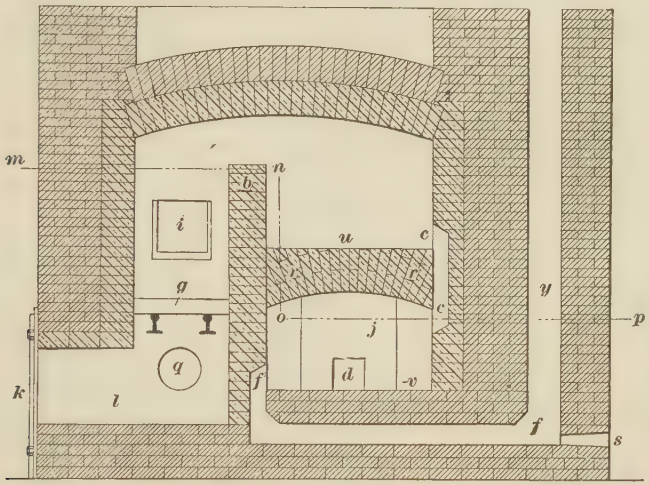

Fig. 6

through an opening at the foot of the stack, toward which the hearth slopes. A blast of from 4 to 12 ounces is supplied to the fire by the blast pipe *t*, Figs. 3, 4, and 5 (*a*), which is attached to one end of the ash-pit. Usually, the blast is obtained from the fan that furnishes blast for the forges.

In some cases, the counterweights for the doors are placed at the side of the furnace, so as to leave the top clear. A boiler may then be set above the furnace, and the heat from the waste gases utilized to furnish steam for steam hammers, for engines driving the fans, etc., the gases being led up under the boiler before they pass up the stack and are allowed to go to waste.

6. Double-Decked Reverberatory Furnace.—In some shops where a variety of work is done and yet where there is

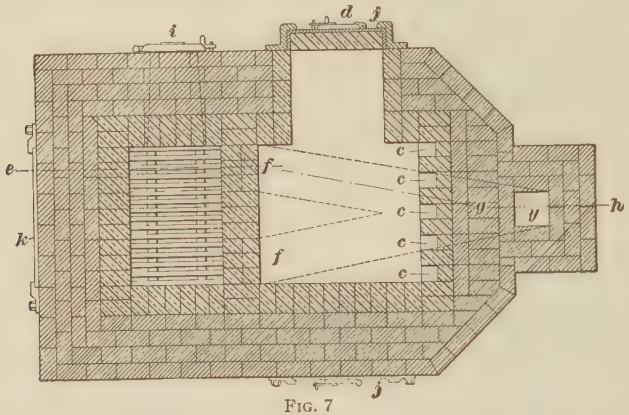

FIG. 7

not enough heavy forging to warrant the installation of a large reverberatory furnace, the double-decked reverberatory furnace shown in Figs. 6 and 7 will be of service. Fig. 6 shows a section along the line *e f g h* of Fig. 7, and Fig. 7 shows a section along the line *m n o p* of Fig. 6; the same reference letters designate the same parts in both illustrations. In this furnace, the grate *g*, ash-pit *l*, fire-door *i*, ash-pit door *k*, and blast-pipe connection *q* are arranged as in the reverberatory furnace already described. When the flame passes over the bridge wall *b*, it enters a relatively small chamber with a hearth *u*, on which is placed the work that is to be heated to a high temperature. After it passes over the hearth *u*, the flame passes through the openings *c* to the lower hearth *v*, and

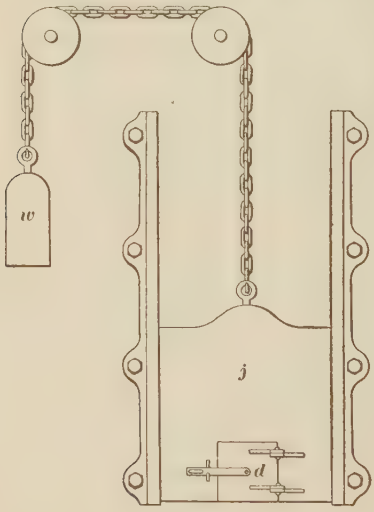

FIG. 8

thence through the openings, or flues, *f* to the chimney *y*. The lower hearth *v* is used for heating work for tempering, annealing, case-hardening, etc.

7. The door for the upper hearth, which is on one side of the furnace, is not shown in Fig. 6; and the door *j* for the lower hearth is on the other side. The slag hole *s* is at the base of the chimney. The detailed arrangement of the furnace doors *j* for closing the large openings is shown in Fig. 8. Each door contains a smaller door *d*, which may be opened to see the condition of the work, or through which small pieces may be introduced. The main doors are counterbalanced by weights *w*. The advantage of placing the fire-door at one side of the furnace is that the fire can be spread more evenly than with the door at the end of the furnace, since the coal can be raked along the length of the bridge wall so as to maintain an even fire at all points.

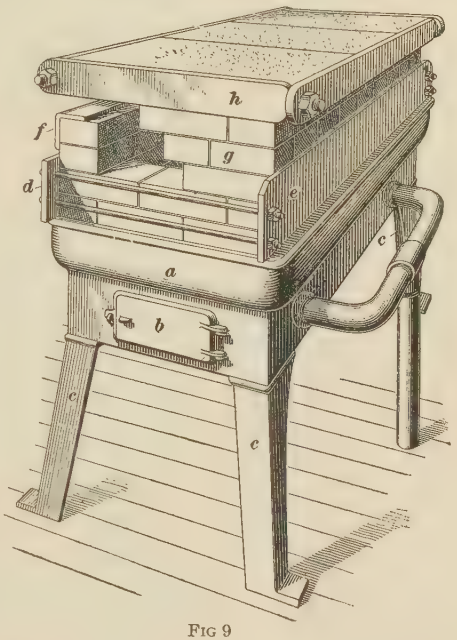

FIG 9

8. Furnace for Long Work.—In shops where long pieces, such as angles and other structural shapes, must be heated, a furnace of the form shown in Fig. 9 will be found useful. It consists of a cast-iron pot, or box *a*, which serves as an ash-pit and on the upper surface of which the grate bars are arranged. The ashes are removed through the door *b* and the blast is furnished through a pipe connected at the back of the ash-pit. Directly above the cast-iron box *a*, which is supported on

cast-iron legs *c*, is a section supported by the plates *d* and *e*, which are held in place by bolts. Above the plate *d* is an angle iron *f*, which protects the front edge of the furnace. The back wall and a part of the ends of the furnace are built up with brick *g*, and the cover or roof is made of several firebrick slabs held together by iron binders *h*; a coke fire is maintained in the furnace.

9. Long work may be laid so that its ends project through the open ends of the furnace, permitting it to be heated the whole length of the fire. This furnace will be found especially useful in heating long angle irons in the center for bending. When curved or irregular pieces must be heated, the cover is frequently lifted off while the work is being placed in the furnace and then replaced during the heating. If large numbers of short pieces are to be heated on the ends only, the pieces are laid across the angle iron *f*, Fig. 9, and allowed to project into the fire. When the furnace is not in use for heating long work, the openings in the ends can be closed temporarily with firebrick. Such a furnace as this is generally used in a large open building where structural shapes are put together, and hence the escaping gases are not objectionable. If the furnace is to be used indoors in winter, an exhaust pipe to carry away the gases can be arranged at the back of the furnace.

10. Special Heating Furnace for High Temperatures.—When a large amount of work is to be heated, it is often convenient to make the process continuous by using a conveyer that will carry the work slowly through the furnace, the cold pieces being placed on the conveyer at one end of the furnace and removed at the other end properly heated for forging. Such a furnace is shown in Fig. 10. The conveyer consists of a series of small trucks *a* that carry fireclay blocks *b* on which the work *c* is placed at one end *f* of the furnace and carried through to the other end, by which time it is thoroughly heated. The trucks then return empty along a track under the furnace, to be loaded again with work. A metal casing *e* surrounds the blocks *b* on the return, so as to prevent undue loss of heat.

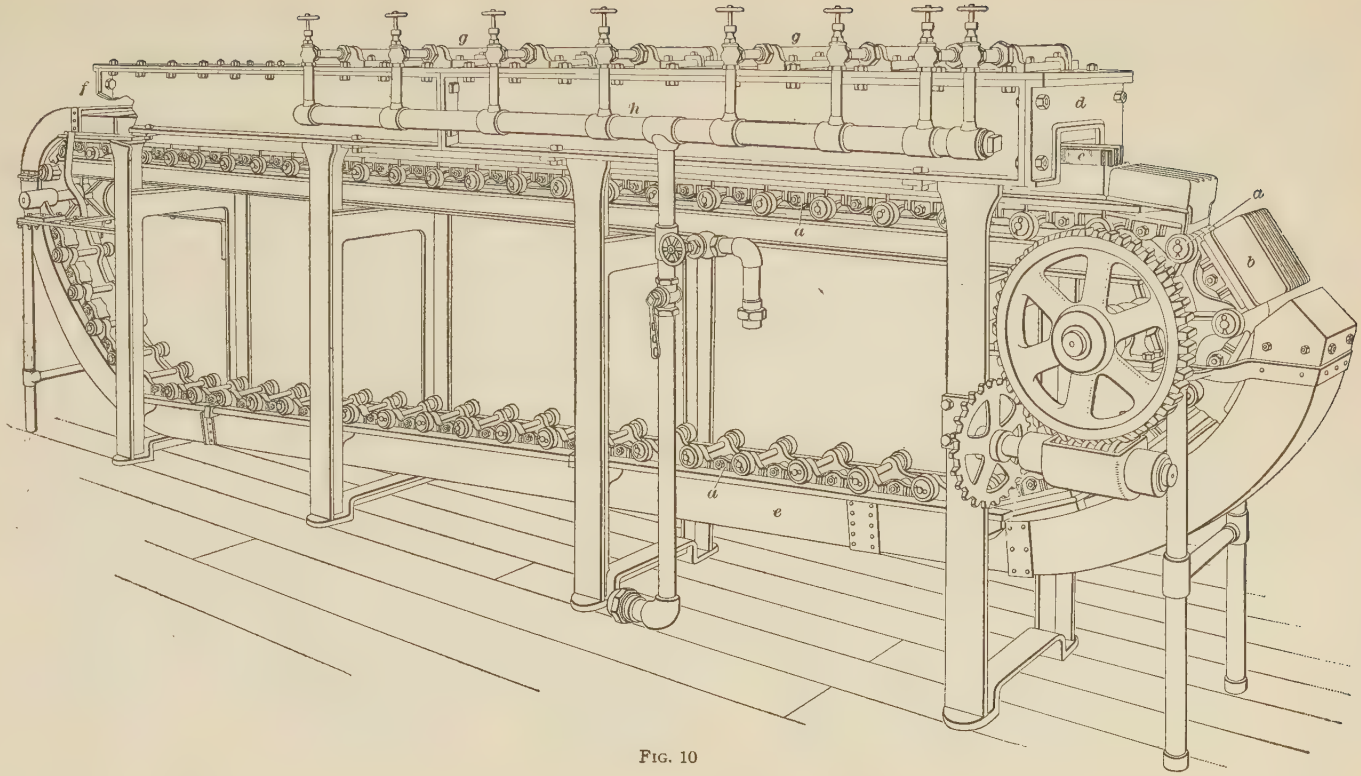

FIG. 10

11. The furnace *d*, Fig. 10, is a rectangular iron box lined with firebrick, and is heated by gas burners *g*, placed on the top of the furnace and supplied by a pipe *h* extending along the side. The trucks do not enter the furnace, because the temperatures are too great to be withstood by cast iron, but the fireclay blocks project into the flame.

The burners can be controlled separately, so that any desired temperature may be obtained. They are placed so as to direct the flame toward the end *f*, so that as the work enters the furnace it is first heated by the blocks on which it rests, then by the hot gases, and finally by the flame under which it passes.

MISCELLANEOUS OPERATIONS AND DATA

FORGING STRUCTURAL SHAPES

12. Bending Angles.—With the more general use of structural shapes and plates, such as angle iron, I beams, deck beams, etc., it has become necessary to bend them into various shapes or forms. Where a considerable amount of this class of

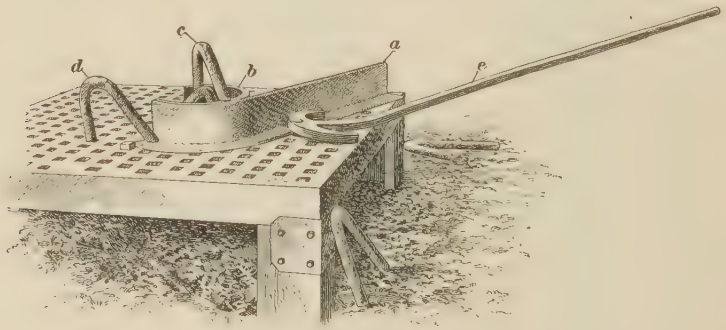

FIG. 11

work is to be done, **bending plates**, Fig. 11, are used; these are large surface plates with holes in their surfaces, in which are fixed the dogs and clamps for holding the work. For bending the angle *a* to the desired curve, the form *b* is first

clamped to the bending plate by means of a **dog** *c*; the end of the angle is also held down by means of a dog *d*. These dogs are simply curved pieces of metal that are sprung into the holes in the plate and driven down into contact with the work.

13. The angle is bent around the form by means of a **moon** *e*, Fig. 11, which is a crescent-shaped piece of metal secured to a long arm and provided with a pin or tongue near the end. This tongue is dropped into one of the holes in the plate, and the angle is bent by sweeping the moon around. Of course, as the angle bends, the outer edge of the projecting flange will be stretched and drawn thin, and care must be taken to see that it does not buckle. By careful handling, very sharp curves can be bent in this way. Fig. 12 (*a*) shows an angle

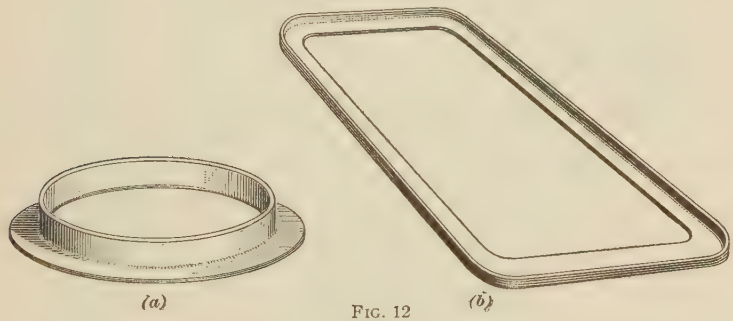

FIG. 12

that has been bent into a circle and afterwards welded, and (*b*) shows an angle bent to form the frame for a door; both of these were bent around forms by the use of moons. Large bending floors, made up of several bending plates laid side by side, are used in bending very large work. Forms made of iron or steel bars bent to the proper shape are clamped on the bending floor with dogs, as shown in Fig. 13. The piece to be bent is then forced around the form by means of moons.

14. Welding Angles.—In some classes of work, it is often necessary to bend angles and other structural shapes to such sharp angles that it is impossible to make the metal flow to the desired form. Four examples of this nature are shown in Fig. 14. In making the piece shown in (*a*), it is necessary to

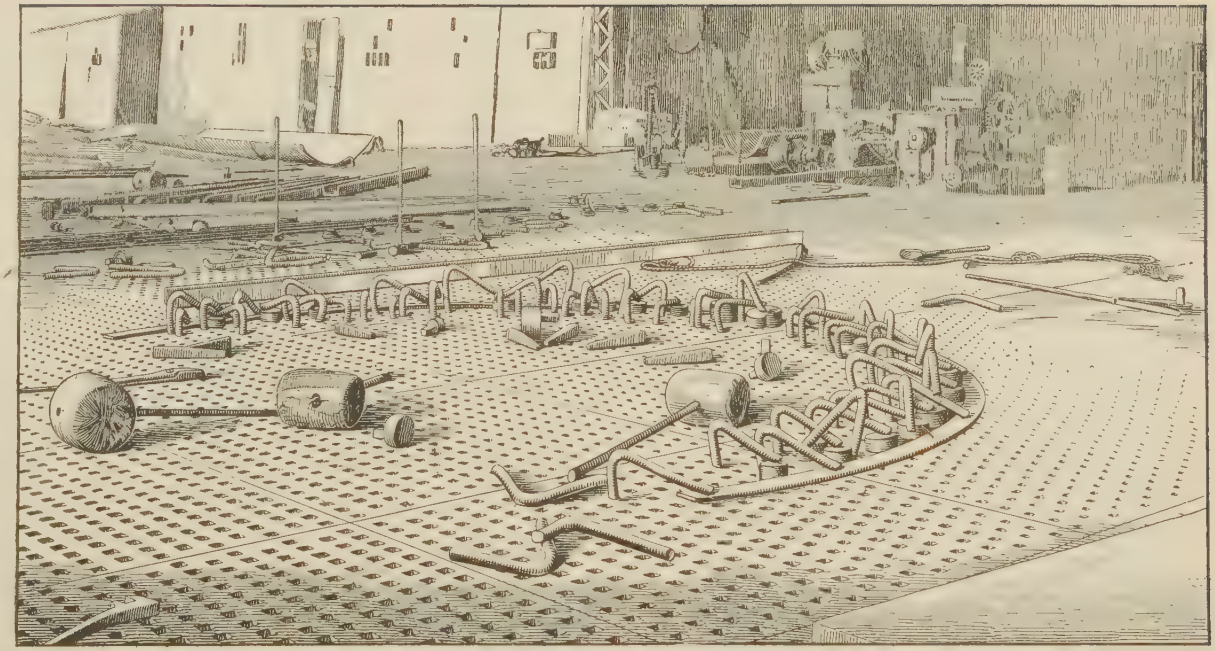

FIG. 13

cut out a piece of the inside flange of the angle at the point *a*, so that the angle before bending will appear as shown in (*e*). After bending, the faces *b* and *c* are brought together and welded. In like manner, the outer corners *d* and *e* of the piece in (*b*) must be split and pieces welded in after bending. Similarly, pieces must be cut out of, and others welded into, the webs of the pieces shown in (*c*) and (*d*). If the parts are kept

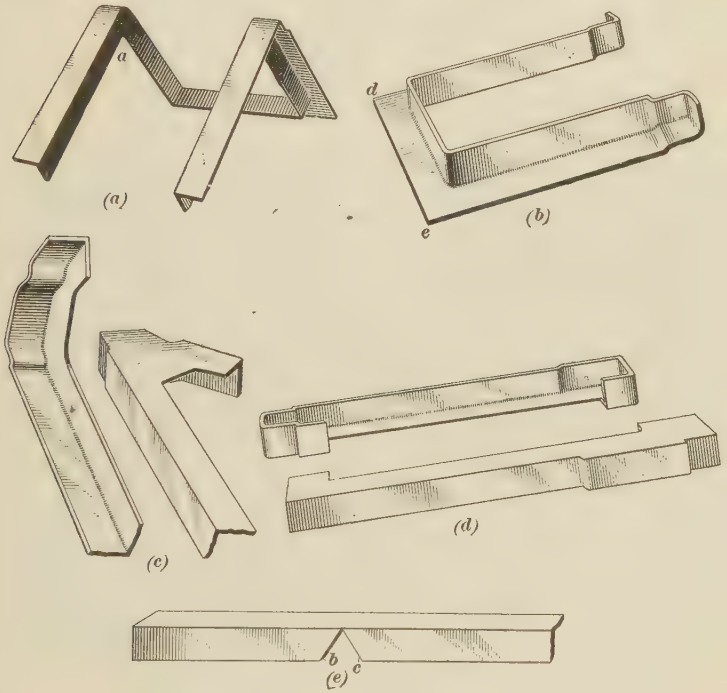

FIG. 14

clean and the fire in proper condition when making these welds, no flux is necessary, as the flux tends, in many cases, only to eat away the surface of the metal.

15. Bending Structural Shapes.—Channels, I beams, deck beams, and other structural shapes are bent by using proper forms. In some cases, it is necessary to have an outline of the sectional shape formed in the side of the former used.

In all work on structural shapes, care must be taken to see that the steel is not heated very far above the point of recalescence, or 1,250° F., except for welding; and any pieces that must be heated to a higher degree should be allowed to cool after they are forged to shape, and then heated to just above the point of recalescence, or 1,250° F., and allowed to cool once more. This will relieve the stresses and restore the fine texture of the metal and insure the greatest possible strength in the piece.

16. Bending Plates.—In bending plates into irregular forms, they are first brought roughly to shape under suitable

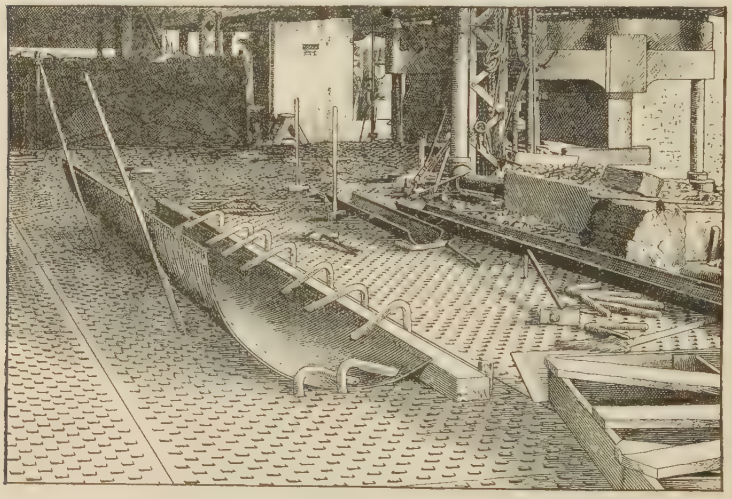

FIG. 15

presses and are then secured to the bending floor by means of dogs, as shown in Fig. 15. Suitable bars or supports are placed at the sides, and the plates formed to a templet by the use of wooden mauls, three of these mauls being shown on the bending floor in Fig. 13. By careful work in this way, a plate can be formed to any required shape.

EFFECT OF REPEATED HEATING ON METAL

17. Effect of Repeated Heating on Cast Iron.—If cast iron is heated repeatedly, it will increase in size with each successive heating; the volume has been increased as much as 40 per cent. This heating opens the grain of the metal and weakens it very greatly. Hence, gray-iron castings should not be exposed to repeated heatings if it is desired that they retain their form and size. This increase of volume of the metal has, however, been put to practical use for increasing the size of parts that have become worn to such an extent that they no longer fill the space for which they were originally intended. To do this, the pieces are packed in air-tight boxes or tubes, heated to a dull red, and then allowed to cool.

18. Effect of Repeated Heating on Wrought Iron or Steel.—It has also been found that repeated heating of wrought iron or low-carbon steel reduces the volume slightly. Advantage may be taken of this shrinkage in cases where it is necessary to reduce slightly the diameters of holes in forgings, or the diameters of rings. If such pieces are heated to a dull red and allowed to cool slowly, or even if they are quenched in water, they will usually be found to have decreased slightly in size.

ESTIMATING STOCK

19. General Rule for Finding Stock.—The work of the blacksmith is such that he is frequently required to estimate the amount of stock of a certain size needed to make a certain piece of work. Usually a dimensioned sketch or drawing of the required piece is given to him and he must then calculate the length of bar stock that must be cut off to make the piece. To accomplish this, the following rule may be used:

Rule.—*Calculate the volume of the required piece in cubic inches and divide it by the area, in square inches, of the stock from which the piece is to be made. The quotient will be the required length of stock, in inches.*

If the piece to be forged is not of the same shape throughout, it may be considered as being made up of several parts. The volumes of these separate parts should be calculated, and their sum will then be the total volume of the piece.

The foregoing rule does not include any allowances for losses during the forging operation, nor for waste due to the trimming off of rough ends so as to obtain a sound forging. Such allowances cannot be fixed by any general rule, because they vary according to the nature and size of the work and are determined largely by experience.

20. In the calculation of the volume of a piece of work of round or rectangular section, the area of cross-section is used. To save time and labor, the cross-sectional areas of round and square steel bars of various sizes are given in Table I at the end of this Section. The first column gives the side of the square bar or the diameter of the round bar, in inches; the second and third columns give the weights per foot of square and round bars, respectively, of the different sizes; and the last two columns give the areas corresponding to the various sizes of square and round bars. Tables II and III give simply the weights per foot of square, round, and flat wrought-iron bars. These two tables, as well as the first three columns of Table I, may be used to find the weight of a bar of iron or steel of a given size and length.

For example, suppose it is desired to know what length of stock $1\frac{1}{2}$ inches square will be required to make a piece 12 inches long, 2 inches wide, and $\frac{3}{8}$ inch thick. The volume of the required piece is $12\times2\times\frac{3}{8}=9$ cubic inches. According to Table I, the area of cross-section of a bar $1\frac{1}{2}$ inches square is 2.25 square inches. Hence, applying the rule of Art. **19**, the length of stock required is

$$9\div2.25=4 \text{ inches}$$

21. General Rule for Drawing or Upsetting.—The work of the blacksmith frequently involves drawing and upsetting operations. For example, he may find it necessary to draw a piece of square stock to a smaller square, or to a round section, or perhaps to a rectangular shape, and he may

wish to know how long the piece will be after it has been drawn out. On the other hand, it may be necessary for him to upset a piece to a larger cross-section, and he may wish to calculate the finished length. No matter whether the operation is drawing or upsetting, or whether the stock is round, square, or any other shape, the general rule to be used is as follows:

Rule.—*Calculate the volume of the original piece in cubic inches and divide it by the area, in square inches, of the cross-section to which it is to be forged. The quotient will be the final length of the piece, in inches.*

If the piece of stock is to be forged to different shapes and sections at different points, it should be considered as being made up of several parts, and the length of each should be calculated by the foregoing rule.

The method of using this general rule can best be illustrated by means of examples and their solutions. To begin with a simple case, suppose that a piece of iron 1 inch square and 2 inches long is drawn out to a bar $\frac{1}{2}$ inch square, and that the final length of the piece is to be calculated. The volume of the original stock is $1\times1\times2=2$ cubic inches. The cross-section of a bar $\frac{1}{2}$ inch square is $\frac{1}{2}\times\frac{1}{2}=\frac{1}{4}$ square inch. Then, according to the rule, the length of the piece, when drawn out, is $2\div\frac{1}{4}=\frac{2}{1}\times\frac{4}{1}=8$ inches.

22. As a further example, suppose that the original piece of stock is to be drawn down to a round bar $\frac{3}{4}$ inch in diameter. The area of cross-section of this round bar would be .4418 square inch, according to Table I. Then, according to the rule of the preceding article, the length of the round bar would be $2\div.4418=4.53$ inches, or approximately $4\frac{17}{32}$ inches.

Again, suppose that the cross-section of the finished piece was to be rectangular, and to measure $1\frac{1}{4}$ inches by $\frac{5}{8}$ inch. The area of such cross-section is $1\frac{1}{4}\times\frac{5}{8}=\frac{5}{4}\times\frac{5}{8}=\frac{25}{32}$ square inch. The length of the finished piece, therefore, would be $2\div\frac{\frac{25}{32}}{}=\frac{2}{1}\times\frac{32}{25}=\frac{64}{25}=2.56$ inches, or approximately $2\frac{9}{16}$ inches.

As a further example, suppose that a piece of round bar $1\frac{1}{2}$ inches in diameter and 3 inches long is to be drawn down to a rectangular piece 2 inches by $\frac{1}{2}$ inch in section and that the

length of the rectangular piece is to be found. According to Table I, the cross-sectional area of a round bar $1\frac{1}{2}$ inches in diameter is 1.7671 square inches. The length of the piece of $1\frac{1}{2}$-inch stock is 3 inches, and therefore the volume must be $1.7671 \times 3 = 5.3013$ cubic inches. The cross-sectional area of the rectangular piece is $2 \times \frac{1}{2} = 1$ square inch. Applying the rule of Art. **21**, therefore, the length of the rectangular piece will be $5.3013 \div 1 = 5.3013$ inches, or about $5\frac{5}{16}$ inches.

23. Stock Required for a Y.—Suppose that it is desired to find the length of stock, $\frac{1}{2}$ inch by $1\frac{1}{2}$ inches in section, required

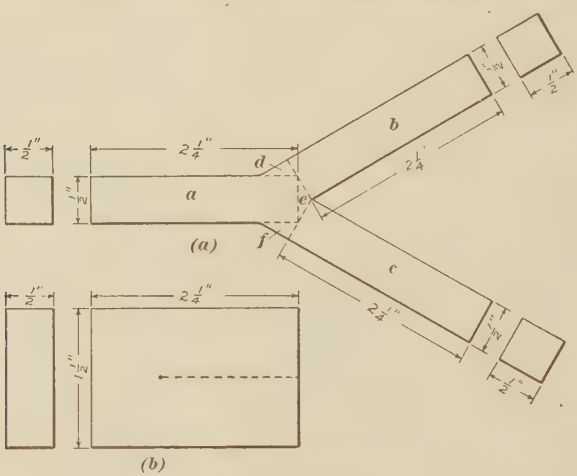

FIG. 16

to form a Y having the dimensions shown in Fig. 16 (*a*). The Y may be considered as being composed of three equal arms *a*, *b*, and *c*, each $\frac{1}{2}$ inch square in section and $2\frac{1}{4}$ inches long. The volume of each of these pieces is $\frac{1}{2} \times \frac{1}{2} \times 2\frac{1}{4} = \frac{9}{16}$ cubic inch, and the volume of all three is $3 \times \frac{9}{16} = \frac{27}{16} = 1\frac{11}{16}$ cubic inches. The cross-sectional area of the stock to be used is $\frac{1}{2} \times 1\frac{1}{2} = \frac{1}{2} \times \frac{3}{2} = \frac{3}{4}$ square inch. The length of stock required, therefore, according to the rule of Art. **21**, is $1\frac{11}{16} \div \frac{3}{4} = \frac{27}{16} \times \frac{4}{3} = \frac{9}{4} = 2\frac{1}{4}$ inches, as shown in (*b*). This calculation, it will be observed, does not take account of the small amounts of material at *d*, *e*, and *f* in (*a*); consequently, the calculated length, $2\frac{1}{4}$ inches, will not

give sufficient stock. However, the amount of material at *d*, *e*, and *f* is very slight, and in small work may usually be neglected. If it must be allowed for, the length of the stock may be increased according to the judgment of the blacksmith, in this case about $\frac{1}{8}$ inch, making the piece of stock $2\frac{3}{8}$ inches long. The stock is first split as indicated by the dotted line in (*b*), for two-thirds of its length, after which the arms are spread and the three sections are drawn down to the shape and size given in (*a*).

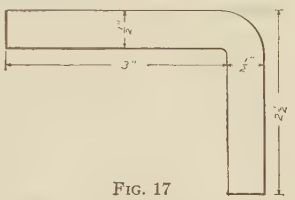

FIG. 17

24. Stock Required for Square Bend.—If a piece of stock of uniform section is to be bent, as shown in Fig. 17, so that the two legs shall be of certain required lengths and at right angles to each other, the length of straight bar required may be calculated by the following rule:

Rule.—*To the length of one leg, measured on the inside of the bend, add the length of the other leg, measured on the outside of the bend, and to their sum add $\frac{1}{8}$ inch. The result will be the length of straight bar required.*

Suppose a piece of iron $\frac{1}{2}$ inch square is to be bent to the size and shape indicated in Fig. 17 and it is desired to know the length of straight stock required. The length of one leg, measured on the inside of the bend, is 3 inches, and the length of the other, measured on the outside of the bend, is $2\frac{1}{2}$ inches. By the rule, the length of straight stock required is $3+2\frac{1}{2}+\frac{1}{8}=5\frac{5}{8}$ inches.

25. Stock Required for Bolt.—A bolt may be made by cutting off a piece of round bar of sufficient length and upsetting

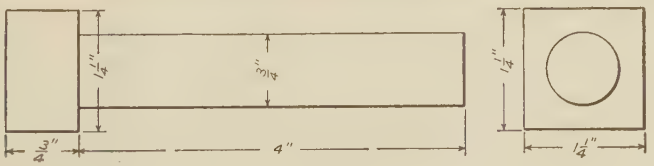

FIG. 18

one end to form the bolt head. Suppose that a bolt $\frac{3}{4}$ inch in diameter and 4 inches long is to be made from $\frac{3}{4}$-inch round

stock, and that the length of stock is to be found. The bolt will have the dimensions shown in Fig. 18. It may therefore be considered as being made up of a cylindrical shank $\frac{3}{4}$ inch in diameter and 4 inches long, and a head $1\frac{1}{4}$ inches square and $\frac{3}{4}$ inch thick. Since the shank is of the same diameter as the stock, $\frac{3}{4}$ inch, and 4 inches long, it will require a piece of stock 4 inches long. The volume of the bolt head is $1\frac{1}{4}\times1\frac{1}{4}\times\frac{3}{4}=1.17$ cubic inches. The area of $\frac{3}{4}$-inch round stock is .4418 square inch, according to Table I. The stock required for the head, therefore, is $1.17\div.4418=2.65$ inches, or approximately $2\frac{5}{8}$ inches. Then, the total length of stock required is $4+2\frac{5}{8}=6\frac{5}{8}$ inches.

If the bolt is to be made by drawing down a piece of square stock, the same method may be followed. The cylindrical shank $\frac{3}{4}$ inch in diameter has an area of .4418 square inch,

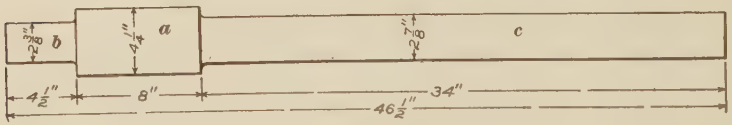

Fig. 19

according to Table I. Its volume, therefore, is $.4418\times4=1.77$ cubic inches, and the volume of the head, as already calculated, is 1.17 cubic inches. Then the total volume of the bolt is $1.77+1.17=2.94$ cubic inches. Suppose that stock $1\frac{1}{4}$ inches square is to be used. Its cross-sectional area is $1\frac{1}{4}\times1\frac{1}{4}=\frac{25}{16}=1.56$ square inches. Therefore, the length of $1\frac{1}{4}$-inch square stock required will be $2.94\div1.56=1.88$ inches, or practically $1\frac{7}{8}$ inches.

26. Stock Required for Solid Shaft.—Suppose that a solid steel shaft of the size shown in Fig. 19 is to be forged from $4\frac{1}{4}$-inch round stock, and that the length of stock needed is to be found. The rough forging may be considered as being composed of three cylindrical parts; but as the middle part *a* is $4\frac{1}{4}$ inches in diameter, or of the same size as the stock to be used, its volume need not be calculated. The end parts *b* and *c* will be forged by drawing down $4\frac{1}{4}$-inch stock. The volume of

each end must therefore be calculated. The area of a circle $2\frac{3}{8}$ inches in diameter is 4.4301 square inches, according to Table I, and that of a circle $2\frac{7}{8}$ inches in diameter is 6.4918 square inches. The volume of the part *b*, therefore, is $4.4301 \times 4\frac{1}{2} = 19.9$ cubic inches, and of the part *c* is $6.4918 \times 34 = 220.7$ cubic inches. The total volume of the parts *b* and *c* is $19.9 + 220.7 = 240.6$ cubic inches. The area of $4\frac{1}{4}$-inch stock is 14.186 square inches; hence, by the rule of Art. **19**, the length of $4\frac{1}{4}$-inch stock required for the ends is $240.6 \div 14.186 = 17$ inches, nearly. To this must be added the 8 inches required for the part *a*, giving a total of 25 inches as the length of stock required for the forging.

27. Another way of working out this problem is to use the weights per foot of round steel of different sizes, as given in Table I. As before, let the shaft be considered as being composed of three cylindrical parts. The part *b* is $4\frac{1}{2}$ inches, or $4\frac{1}{2} \div 12 = \frac{3}{8}$ foot, long, and $2\frac{3}{8}$ inches in diameter. According to Table I, the weight of 1 foot of $2\frac{3}{8}$-inch round steel is 15.06 pounds; hence, the weight of $\frac{3}{8}$ foot is $\frac{3}{8} \times 15.06 = 5.6$ pounds. The part *c* has a length of $34 \div 12 = 2\frac{5}{6}$ feet, and its weight is $2\frac{5}{6} \times 22.07 = 62.5$ pounds. The total weight of the ends *b* and *c*, then, is $5.6 + 62.5 = 68.1$ pounds. The stock to be used is $4\frac{1}{4}$ inches in diameter and weighs, according to Table I, 48.24 pounds per foot. The length of stock required for the ends, therefore, is $68.1 \div 48.24 = 1.412$ feet, or $12 \times 1.412 = 16.94$ inches, or approximately 17 inches, as before. The middle part *a* requires 8 inches of stock. Therefore, the total length of stock required is $17 + 8 = 25$ inches.

28. Stock Required for Crank-Shaft.—Suppose that a steel crank-shaft is to be forged from a rough ingot and that the completed forging is to have the form and size shown in Fig. 20 (*a*). The parts *a* and *b*, from which the cranks are formed, as indicated by the dotted lines, are 29 inches wide and 13 inches thick; therefore, the first step in forging is to draw the ingot down to a bar of rectangular cross-section 29 inches by 13 inches. The parts *c*, *d*, and *e* are then made by drawing down the rectangular bar at the proper places. The length of

rectangular stock required is equal to the volume of the crank-shaft forging, in cubic inches, divided by the area of the rectangular cross-section, in square inches. The volume of each of the parts *a* and *b* is $23 \times 29 \times 13 = 8{,}671$ cubic inches, and the volume of both is $2 \times 8{,}671 = 17{,}342$ cubic inches. The parts *c*, *d*, and *e* are of the same diameter, 10 inches, and their cross-section is therefore 78.54 square inches, according to Table I. The combined length of the three parts is $24 + 58 + 36 = 118$ inches, and the total volume of the three is $78.54 \times 118 = 9{,}268$ cubic inches. The volume of the crank-shaft forging, then, is $17{,}342 + 9{,}268 = 26{,}610$ cubic inches. A section

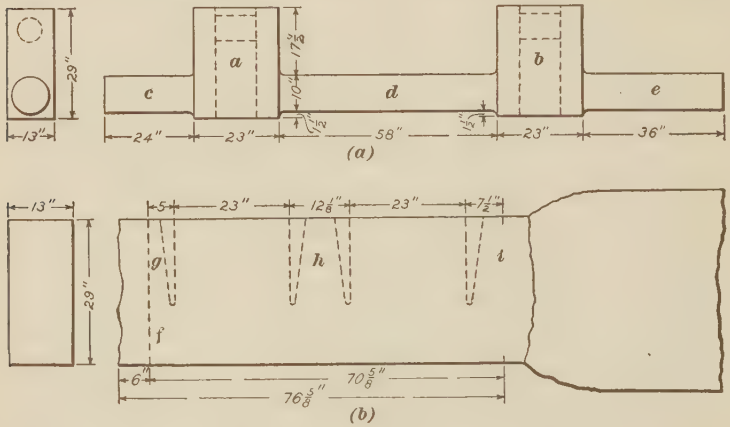

FIG. 20

29 inches by 13 inches contains 377 square inches. The length of stock of this size, therefore, is $26{,}610 \div 377 = 70.6$ inches. To allow for fillets and for trimming the ends, the piece of rectangular stock should have an over-all length of at least $76\frac{5}{8}$ inches, as shown in (*b*). Practically, the piece would be made 78 inches, or $6\frac{1}{2}$ feet long.

29. After a sufficient length of rectangular stock has been drawn down from the ingot, as shown in Fig. 20 (*b*), it must be marked off properly, so that the parts *c*, *d*, and *e* in view (*a*) can be forged. The part *c* has a volume of $78.54 \times 24 = 1{,}885$ cubic inches. The length of rectangular stock required for this part

is $1,885 \div 377 = 5$ inches. As the end of the stock is rough and must be trimmed off, the measurements are made from a point several inches from the end, indicated by the dotted line *f* in (*b*). From the line *f* a distance of 5 inches is laid off, marking the stock required for the part *c*. Next, a distance of 23 inches is laid off, marking the stock required for the crank *a*. The part *d* has a volume of $78.54 \times 58 = 4,555$ cubic inches and requires a length of stock equal to $4,555 \div 377 = 12\frac{1}{8}$ inches; hence, a distance of $12\frac{1}{8}$ inches is laid off, as shown. This is followed by another section 23 inches long, for the crank *b*. The part *e* has a volume of $78.54 \times 36 = 2,827$ cubic inches and requires $2,827 \div 377 = 7\frac{1}{2}$ inches of stock, which is marked off at the right. After the stock has been marked off, as shown, it is heated, and a hack is used to notch it as indicated by the V-shaped cuts. These notches must be square on the faces that form the sides of the parts *a* and *b*, and their depth must be a little less than $17\frac{1}{2}$ inches, which is the length of the crank, measured from the side of the shaft to the outer end. In this particular case, the notches cut by the hack would be between 17 and $17\frac{1}{4}$ inches deep. The metal at *g*, *h*, and *i* is then forged to a circular shape, 10 inches in diameter, thus forming the parts *c*, *d*, and *e*.

30. Avoiding Waste of Stock.—When cutting pieces of material for forging operations, the bar stock selected should be of such length as to enable the pieces to be cut with little or no waste. To illustrate this point, suppose that a number of pieces of steel 9 feet long are required for wagon tires; also, suppose that the supply of stock of the proper size consists of two lots of bars, one lot 10 feet long and the other 18 feet long. If the tires are cut from the 10-foot bars, there will be a waste end 1 foot long cut off each bar; but if the 18-foot bars are used, each will furnish stock for two tires, without any waste. Hence, it would be preferable to use the 18-foot bars. In addition, less cutting would be required to obtain the required number of tires, since each cut would give two pieces; whereas, if the shorter bars were used, each cut would give only one piece, besides causing a waste of 1 foot.

31. Stock Required for Circular Ring.—When a piece of straight stock is bent to a curve, the material at the outer side of the bend is stretched and that on the inner side is compressed. The length of the center line of the piece, however, changes little, if any. If it is desired to find the length of straight stock needed to form a circular ring, the following rule should be used:

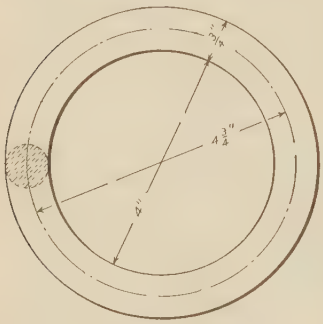

FIG. 21

Rule.—*To find the length of straight stock required for a circular welded ring, multiply the diameter of the ring, measured from center to center of stock, by 3.1416, and to the product add half the thickness of the stock.*

For example, suppose that a ring of the size shown in Fig. 21 is to be made and that the length of straight stock required for it is to be found. The inside diameter of the ring is 4 inches, and the diameter of the stock is $\frac{3}{4}$ inch; hence, the diameter from center to center of stock is $4\frac{3}{4}$ inches. Then, applying the rule, the length of straight $\frac{3}{4}$-inch stock required is $(4\frac{3}{4}\times 3.1416)+(\frac{1}{2}\times\frac{3}{4})=15+\frac{3}{8}=15\frac{3}{8}$ inches. The addition of half the thickness of the stock is made to allow for loss of material in welding. The same rule holds true for square, hexagonal, or oval stock bent to a circular ring.

32. The link shown in Fig. 22 is known as a *figure-8 link* and is bent to shape without welding. It may be considered as being made up of two circular rings, since each end of the link has an approximately circular form; and as the link is not welded, no allowance for welding need be made. The rule to be used, therefore, is as follows:

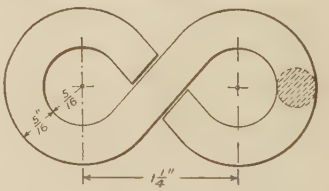

FIG. 22

Rule.—*Considering each end of the link as a circular ring, multiply the diameter of the ring, measured from center to center*

of stock, by 3.1416, and then multiply that product by 2. The result is the length of stock required for the figure-8 link.

Suppose that the length of straight stock for the link shown in Fig. 22 is to be found. The inside diameter of each end is $2\times\frac{5}{16}=\frac{5}{8}$ inch, and the stock is $\frac{5}{16}$ inch in diameter. The diameter of the ring from center to center of stock, therefore, is $\frac{5}{8}+\frac{5}{16}=\frac{15}{16}$ inch. Then, applying the rule, the length of stock required for one end is $\frac{15}{16}\times 3.1416=2.95$ inches, or nearly 3 inches, and for the whole link the stock required is $2\times 3=6$ inches.

33. Stock Required for Chain Link.—A chain link of the form shown in Fig. 23 consists of two equal semicircular ends joined by straight sides. The amount of stock needed for the sides is equal to twice the length of one side of the link; and as the two ends together form a circle, the amount of stock required for them, including the allowance for the weld, may be calculated by the rule of Art. **31.** For example, suppose that the link is to have the dimensions marked on it in the illustration and that the length of straight stock required for it is to be found. The length of $\frac{3}{8}$-inch round stock required for the two straight sides is $2\times\frac{5}{8}=1\frac{1}{4}$ inches. The two semicircular ends together form a ring whose inside diameter is $2\times\frac{5}{16}=\frac{5}{8}$ inch, and whose diameter from center to center of stock is $\frac{5}{8}+\frac{3}{8}=1$ inch. According to the rule of Art. **31,** therefore, the stock required for the two ends is $(1\times 3.1416)+(\frac{1}{2}\times\frac{3}{8})=3\frac{1}{8}+\frac{3}{16}=3\frac{5}{16}$ inches. The total length of straight stock needed to form the link, then, is $1\frac{1}{4}+3\frac{5}{16}=4\frac{9}{16}$ inches.

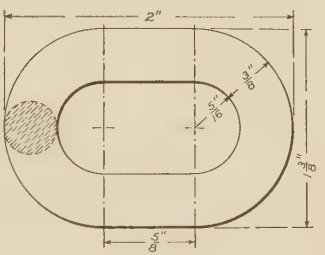

FIG. 23

34. Stock Required for Irregularly Curved Work. If a piece of work is made up of one or more irregular bends, so that none of the rules previously given can be used to find the length of straight stock needed, then the length of the center line must be found; for it has already been stated that,

when a bar is bent, the center line remains practically unchanged in length. If the length of the center line is found, therefore, the length of straight stock needed will be known. One way of doing this is to take a piece of soft wire of sufficient length and bend it to the shape of the desired piece along the center line. When straightened out, the length of this wire will be the length of straight stock required. Another way is to mark the center line on the work and then with a pair of dividers set to a convenient dimension, to step off divisions along the center line from one end to the other. The number of divisions thus obtained multiplied by the distance between the points of the dividers is the length of the center line, and also of the stock required.

35. In case the amount of upsetting is great, or if the piece is to be machined to size after forging, the amount of stock required is greater than the volume of the finished piece. Suppose, for example, that a cylindrical cutter blank is to be made, the finished size of which is to be $7\frac{1}{2}$ inches in diameter and $1\frac{1}{4}$ inches thick; and, further, suppose that the available stock is 4 inches in diameter. It will be necessary to cut off a piece of this 4-inch stock and upset it to a size larger than the finished blank, so that there will be ample allowance for machining. In the problem assumed, the rough forging would be upset to a diameter of 8 inches and a thickness of $1\frac{1}{2}$ inches. The cross-sectional area of a forging 8 inches in diameter is 50.266 square inches, according to Table I. Then the volume of the forging is $50.266 \times 1\frac{1}{2} = 75.4$ cubic inches. The cross-sectional area of 4-inch round stock is 12.566 square inches. Then, according to the rule of Art. **19,** the length of stock required is $75.4 \div 12.566 = 6$ inches.

36. Finding Volume by Water Displacement.—It may happen that a forging of irregular form is made as a sample or specimen piece, and that it is then desired to know the amount of stock required to make duplicate pieces. If the work is of very irregular shape, so that the calculation of its volume is apt to be difficult, the desired result may be obtained in another way. A tub with straight sides is filled to overflowing

with water. Then the piece whose volume is to be found is lowered into the tub until it is entirely submerged in the water. Some of the water will thus be displaced and flow over the edge of the tub. The piece is next lifted out, and it will be found that the water level is then below the edge of the tub. The volume of water thus forced out of the tub represents the volume of the piece, and is equal to the cross-sectional area of the tub multiplied by the distance from the top of the tub to the surface of the water. If the piece that is lowered into the water is a machined forging, the volume found will be the volume of the finished piece, and this will need to be increased by a certain allowance to obtain the volume of the rough forging. The length of stock required can then be found by the rule of Art. **19.** To have this method give reasonably accurate results, the tub or vessel used should be just large enough to contain the piece of work when fully submerged.

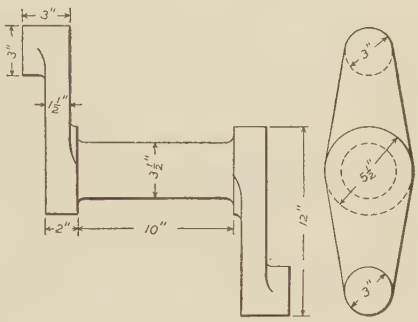

FIG. 24

37. As an example, suppose that it is desired to know what length of $5\frac{1}{2}$-inch round stock will be required to make the rough forging from which the finished piece in Fig. 24 is machined. Let it be assumed that, when the finished piece has been submerged in a filled tub 20 inches in diameter and withdrawn, the water level in the tub is $\frac{15}{16}$ inch below the edge. The volume of water that must have been displaced by the piece is then $20^2 \times .7854 \times \frac{15}{16} = 294.5$ cubic inches. To make allowance for finish, the rough forging must be larger than the finished piece. With careful workmanship, an allowance of 5 per cent. in volume is sufficient; that is, the volume of the rough forging is taken as 5 per cent. more than that of the finished piece. The rough forging must therefore contain $294.5 + (.05 \times 294.5) = 294.5 + 14.7 = 309.2$ cubic inches. The stock used is $5\frac{1}{2}$ inches in diameter and has a cross-section

of 23.8 square inches. The length of stock required, therefore, is $309.2 \div 23.8 = 13$ inches.

38. Shrinking on a Link.—Machine parts are often held together by links or bars shrunk on. An example of this construction is shown in Fig. 25, in which *a* is a steel link that is shrunk on the bosses *b* and *c*, which form projections on the pieces *d* and *e*, respectively. The link is made of such size that, when heated to a red heat, it will just slip over the bosses *b* and *c*. As it cools, it shrinks, and the parts *d* and *e* are thus held together very tightly. The increase in the length and width of the link while being heated to a red heat is slight, amounting to a very few hundredths of an inch; consequently, it is useless to calculate the size of the cold link with a view to making allowance for heating and shrinking. The link is simply made smaller than the inside dimensions marked, and is heated to redness and tried on the bosses. If it will not go on, it is drawn a little, heated, and tried again, and these operations are repeated until the red-hot link can just be slipped over the bosses.

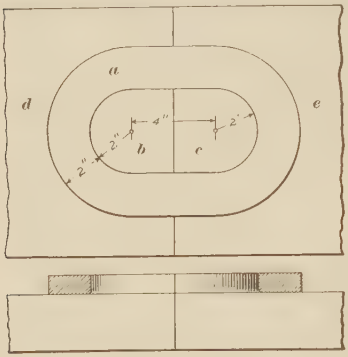

Fig. 25

39. Stock Required for Bushing.—If a cylindrical steel bushing is to be forged from a piece of solid round stock, a hole is first drilled lengthwise through the center of the stock. The piece is then heated, a mandrel is inserted, and the work is forged to the desired size, the size of the mandrel being changed as the hole grows larger. Suppose that the rough forging of a bushing is to have the dimensions shown in Fig. 26; also, that the length of stock to be used is 6 inches, that a $1\frac{1}{2}$-inch

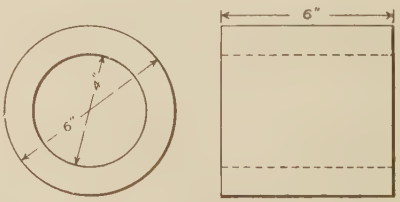

Fig. 26

hole is to be drilled in it, and that its diameter is to be found. The cross-section of the rough forging is the difference between the area of a 6-inch circle and the area of a 4-inch circle, or, according to Table I, $28.274 - 12.566 = 15.708$ square inches, and the volume is $6 \times 15.708 = 94.248$ cubic inches. The original piece of stock must contain this amount of steel, and, in addition, the quantity removed by the drill, which is equal to the volume of a cylindrical piece $1\frac{1}{2}$ inches in diameter and 6 inches long. According to Table I, the area of a $1\frac{1}{2}$-inch circle is 1.7671 square inches; then the volume is $1.7671 \times 6 = 10.603$ cubic inches. The volume of the stock, therefore, must be $94.248 + 10.603 = 104.851$ cubic inches. The length of the stock is to be 6 inches; hence, its cross-section must be $104.851 \div 6 = 17.475$ square inches. According to Table I, the area of a round bar most nearly equal to 17.475 square inches is 17.721 square inches and the diameter corresponding to this area is $4\frac{3}{4}$ inches; therefore, a piece of stock $4\frac{3}{4}$ inches in diameter and 6 inches long would be drilled with a $1\frac{1}{2}$-inch hole and forged to the size indicated. To keep the length from increasing, the piece must be upset repeatedly during the forging.

40. Forging Square From Round.—It is often desirable to know the size of round stock required to produce a square bar of given size, without upsetting. This can easily be done by the use of Table I. The area of the desired square is first found, and then the area of round bar most nearly equal to the area of the square. The diameter corresponding to the area of round bar thus found is the size of round bar that can be forged to the given square without any upsetting. For example, a $1\frac{1}{8}$-inch round bar can be used to give a 1-inch square bar, because the area of the former is .994 square inch, which is very nearly equal to the area of the latter, or 1 square inch. Similarly, a $3\frac{1}{4}$-inch round bar will produce a $2\frac{7}{8}$-inch square bar, because its area, 8.2958 square inches, is approximately equal to the area of the square bar, or 8.2656 square inches.

41. Stock Required for Forged Ring.—Suppose that it is desired to know what length of stock 10 inches square will be required for the rough forging shown in Fig. 27, assuming

that a circular piece 6 inches in diameter is punched out when the stock has been forged to 3 inches in thickness. The forging is rough and varies from 6 to 7 inches in width, as indicated. The average width is $(6+7)\div 2=6\frac{1}{2}$ inches, and the average inside diameter is $30-(2\times 6\frac{1}{2})=30-13=17$ inches. The area of the ring, then, is $30^2\times .7854-17^2\times .7854=707-227=480$ square inches. The thickness is 3 inches; therefore, the volume of the forging is $3\times 480=1{,}440$ cubic inches. The cylindrical piece that is punched out, before the ring is put on a mandrel and forged to size, has an area of 28.274 square inches, according to Table I, and a volume of $28.274\times 3=85$ cubic inches. The volume of stock required, therefore, is $1{,}440+85=1{,}525$ cubic inches. The stock is 10 inches square, corresponding to a cross-section of $10\times 10=100$ square inches; hence, the length needed must be $1{,}525\div 100=15.25$ inches, or $15\frac{1}{4}$ inches.

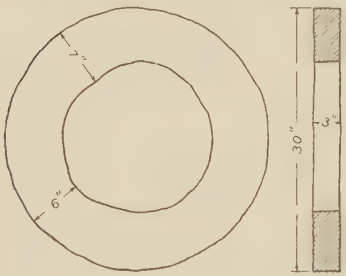

FIG. 27

42. Cutting Stock Without Waste.—It is desirable not to waste stock, particularly if it is expensive material. Suppose, for example, that a bar of tool steel 7 feet long is to be made into cold chisels, each of which requires a piece of stock $6\frac{1}{4}$ inches long. The length of the bar is $7\times 12=84$ inches, and as each chisel needs $6\frac{1}{4}$ inches of stock, there will be enough material for $84\div 6\frac{1}{4}=13\frac{1}{2}\frac{1}{5}$ pieces; that is, the bar will make 13 pieces $6\frac{1}{4}$ inches long, and there will remain a waste end $2\frac{3}{4}$ inches long. This waste can be avoided by dividing it among the 13 pieces, increasing the length of each slightly. The stock for each piece will then have a length of $84\div 13=6\frac{6}{13}$ inches, or almost $6\frac{15}{32}$ inches. Moreover, by dividing the slight excess of stock among the several pieces, the number of cuts on the bar is reduced by one, thus lessening the time, the labor, and the wear on the tools.

43. Stock Required for Valve Link.—The finished piece shown in Fig. 28 (*a*) is a valve link and is used in the

reversing gear of a steam engine. It is forged from a piece of steel $3\frac{3}{4}$ inches square, the successive steps in the forging operation being shown in views (*b*) to (*d*). The stock is first marked out, as shown in (*b*), the widths *a*, *b*, and *c* being the parts that form the circular bosses in (*a*). The stock is then fullered, as shown in (*c*), leaving the parts *a*, *b*, and *c* with square sides,

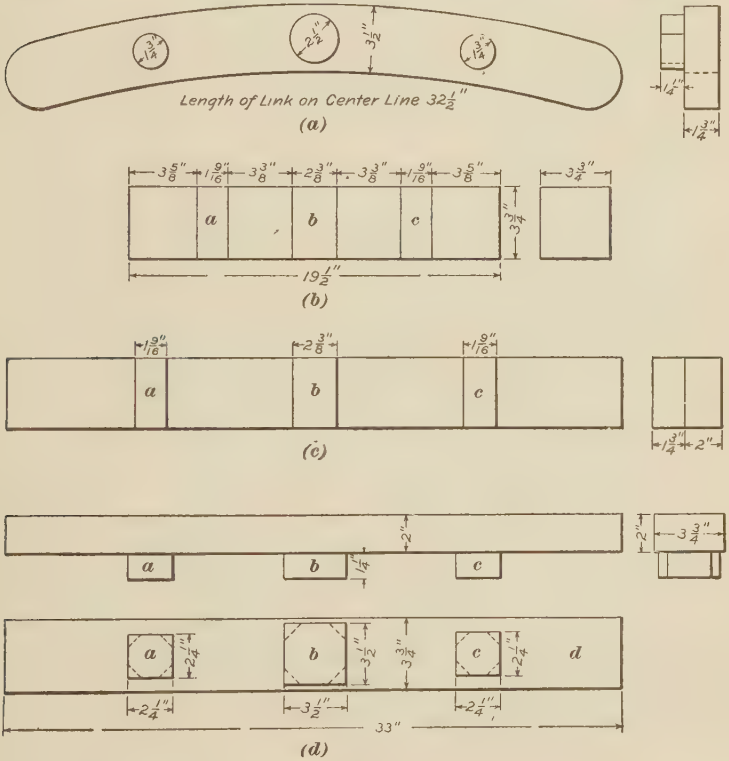

FIG. 28

after which the sections between them, as well as the ends, are drawn down to the form shown in (*d*). Finally, a hot set is used to trim off the corners of the parts *a*, *b*, and *c*, as shown by the dotted lines. The rough forging is then bent to the correct curve and machined to the dimensions given in (*a*). To allow for machining to the sizes given, the rough forging will need to

have the sizes shown in (*d*). The completed forging then consists of four parts, each of rectangular cross-section. The volume of the part *a* is $2\frac{1}{4}\times2\frac{1}{4}\times1\frac{1}{4}=6.3$ cubic inches. The volume of the part *b* is $3\frac{1}{2}\times3\frac{1}{2}\times1\frac{1}{4}=15.3$ cubic inches. The volume of the part *c* is equal to that of *a*, or 6.3 cubic inches. The main part *d* has a volume of $33\times3\frac{3}{4}\times2=247.5$ cubic inches. The volume of the forging, therefore, is $6.3+15.3+6.3+247.5=275.4$ cubic inches. The area of a bar $3\frac{3}{4}$ inches square is 14.063 square inches, according to Table I; hence, the length of stock required is $275.4\div14.063=19.58$ inches, or $19\frac{1}{2}$ inches, approximately.

THERMIT WELDING

44. Thermit.—If aluminum in the form of powder or filings is mixed in the proper proportions with powdered iron oxide and the mixture is set on fire, the oxygen in the iron oxide is taken up by the aluminum; in other words, the aluminum burns to oxide of aluminum and the iron in the iron oxide is set free. The burning of the aluminum is accompanied with great heat, and the temperature of the mixture is raised to about 5,400° F. This is considerably above the melting point of iron; consequently, the effect of the rapid burning is to produce a quantity of highly heated molten iron, as well as a slag consisting of oxide of aluminum. The mixture of aluminum and iron oxide is known as **thermit**, and the high temperature set up by its burning, in connection with the molten iron produced, enables it to be used to advantage in welding broken forgings and castings. The molten metal produced by the burning of thermit is called *thermit steel.*

45. Crucible for Thermit.—Inasmuch as the temperature resulting from the burning of thermit is very high, the vessel in which the action takes place must be built to withstand the heat. This vessel, known as a crucible, is shown partly in section in Fig. 29. The conical sheet-iron shell *a* is lined with a thick layer of refractory material *b* that is strong and able to resist the effects of high temperature. At the bottom of the cone is a circular iron plate *c* with a hole at its center. It

supports a cylindrical block *d* of magnesia, which has a tapered hole through it. In the tapered hole is set the thimble *e*, which has the same taper as the hole. The thimble is also made of refractory material of high grade, because the molten metal is tapped through it. The opening in the thimble is closed, during the burning of the thermit, by an asbestos washer *f*, beneath which is a scarfed pin *g* that hangs freely inside the thimble. On top of the washer is rammed an iron disk *h*, and over the disk is poured a layer of sand *i*.

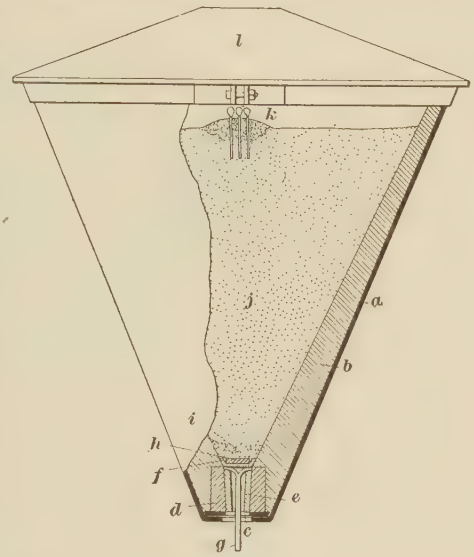

FIG. 29

46. Preparing and Firing Charge. After the plugging material has been placed in the small end of the conical crucible, Fig. 29, the charge of thermit *j* is poured in and leveled on top. Then, in the center of the top surface is placed a teaspoonful of ignition powder *k*, and two or three matches are set into it, with their heads upwards. These matches are now set on fire by the flame of another match, the hand is withdrawn quickly, and the cover *l* of the crucible is put in place. The burning of the thermit charge is violent, and will cause the crucible to vibrate. As soon as the vibration has ceased, the burning is ended, and the thermit steel is ready to be tapped. To do this, the lower end of the pin *g*, which projects below the crucible, is given a sharp blow upwards with the flat end of a tapping spade, or flat iron bar. The asbestos washers and the metal disk are thus displaced and the molten metal runs out through the hole in the thimble and is directed into the mold surrounding the broken

part that is to be welded. The crucible may be supported on a tripod or suspended by a suitable sling.

47. Applications of Thermit.—When a part of a machine breaks, a great deal of time and labor may be required to remove the broken piece and replace it with a new one. If the break can be repaired without taking the part away or dismantling the machine, a considerable saving results. Thermit

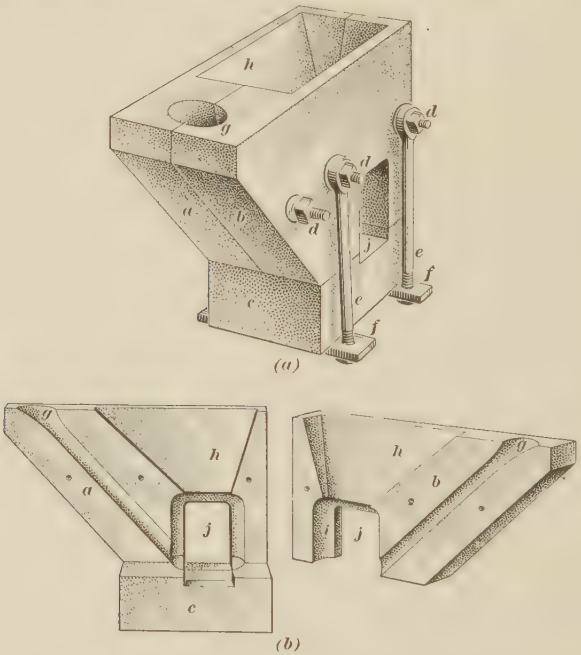

FIG. 30

is used very extensively for mending broken forgings and castings while they are in place, for joining the ends of rails for street-car tracks, and for similar work. The metal at the break is cut away until there is a small space between the ends that are to be joined, and the broken part is carefully lined up and clamped in position. A mold is then built around the break, and the thermit crucible is placed in such a position that the molten steel can be run into the mold. As the highly heated

thermit steel fills the mold, it runs between the ends of the broken piece, and a part of its heat raises the temperature of the ends to the melting point. The result is that the ends and the thermit steel unite in one mass that, when cool, forms a weld joining the parts of the broken piece.

48. Mold for Thermit Welding.—The mold used in making a thermit weld must fit snugly over the work and must be so shaped that a collar of steel will be formed about the weld. If the piece is of regular form, as, for instance, a locomotive frame, a firebrick mold designed especially for making the weld may be purchased. In Fig. 30 (*a*) a mold of this kind is shown assembled. It consists of three pieces *a*, *b*, and *c*, which are shown separated in (*b*). The side blocks *a* and *b* are held together by the three bolts *d*, which pass through from side to side and have washers under the heads and nuts. The bottom piece *c* is clamped to the others by the eye-bolts *e*, which fit over two of the bolts *d* and pass through the straps *f*. The joint surfaces of the firebrick blocks are coated with a thin layer of fireclay before they are bolted together, to insure tight joints. The channel *g* is the pouring gate, which leads the molten steel to the bottom of the break and allows it to rise around the ends to be joined. The opening *h* serves as a riser and the groove *i* forms the collar of metal around the weld. The rectangular frame extends through the opening *j*, and the joints are luted with fireclay.

49. Welding Locomotive Frames With Thermit. By using thermit it is often possible to repair broken locomotive frames without removing them; that is, the welds are made while the parts are in place. Suppose, for example, that a frame breaks at one of the upper corners of a jaw. The first thing to do is to remove enough parts near the fracture so that it will be accessible and so as to make room for a mold about 1 foot wide. Next, a series of holes $\frac{3}{4}$ inch or 1 inch in diameter, depending on the size of the frame, should be drilled along the line of the break, overlapping one another as shown at *a*, Fig. 31 (*a*), and the metal should be chipped away, leaving a gap between the ends. The parts of the frame should then be

placed in correct alinement and two punch marks should be made on the frame, on opposite sides of the break, but far enough from it so as not to be covered by the mold. The punch marks enable a trammel to be used to test the accuracy of alinement when the weld has been completed. The jack *b* is inserted in the jaw and the break is forced open about $\frac{1}{4}$ inch, to allow for contraction when the metal at the weld cools. The exact

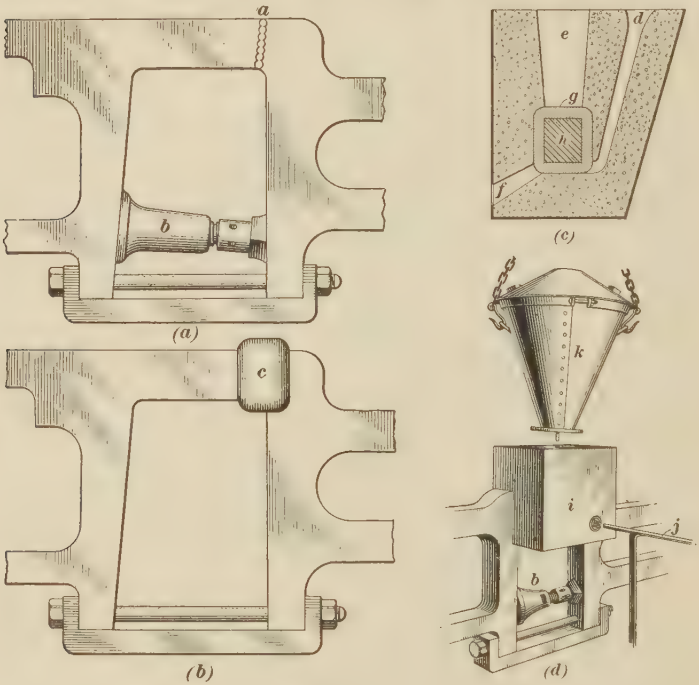

FIG. 31

amount of contraction depends on the width of the collar of metal around the weld, and therefore judgment must be used in making the necessary allowance.

50. The mold that is built around the break must be shaped so as to leave a collar of steel around the weld. This collar should be thickest directly over the break and should overlap the break at least 1 inch on each side. To make the

recess in the mold, a pattern of yellow wax is built up around the break, as shown at *c*, Fig. 31 (*b*), of the same size and shape as the desired collar. The opening or break is also filled with this wax. Then the mold box is secured in place around the broken frame and the mold is rammed up around the wax and the frame. The mold is made of a mixture composed of equal parts of fire sand, good fireclay, and ground firebrick. These materials are mixed while dry and then just enough water is added to make the mixture pack well. The openings for the pouring gate and the riser are made by setting in wooden pins of the proper form. A cross-section of the mold is shown in (*c*), in which *d* is the pouring gate, *e* the riser, and *f* a channel for the insertion of a heating torch. The wax *g* surrounds the frame *h*. The combined volumes of the gate and riser should equal the volume of the collar. The thermit steel should not be allowed to wash, or strike directly against, the ends of the frame during pouring; therefore, the gate should lead to the bottom of the mold, so that the metal will rise around the break.

51. When the mold is completed, it will appear somewhat as shown in Fig. 31 (*d*), in which *i* is the mold box. The wooden pins forming the gate, the riser, and the heating channel are withdrawn from the mold and a torch *j* is inserted through the heating channel. The wax is thus melted, and runs out, leaving an opening of the desired form in the mold. The heating is continued until the mold is thoroughly dry. The thermit crucible *k* is fixed in position above the mold, at a distance of about 4 inches and directly over the pouring gate, and is charged with thermit. The heating by the torch is continued until the frame at the break is at a good red heat. Then the torch is quickly withdrawn and the hole is closed securely with a dry-sand core, backed up by sand. The ignition powder is now placed on top of the thermit and ignited, the cover of the crucible is put on, and as soon as the melting has been completed the steel is tapped from the crucible. The steel will commence to solidify about ten minutes after pouring, at which time the screw jack *b* should be eased off a bit. As the weld continues to cool and contract, the pressure of the jack

should be reduced gradually. The mold should not be removed for at least two hours after pouring, and then the gate and the riser should be trimmed off.

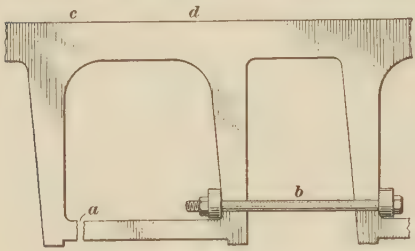

FIG. 32

52. If the break occurs in the lower rail of the frame, as at *a*, Fig. 32, the ends at the break are chipped away, leaving a gap between them. Clamp bolts *b* are put on the adjoining legs and their nuts are tightened, thus drawing the broken ends farther apart. The mold is built up in exactly the same manner as was described in connection with Fig. 31; but in order to prevent the frame from drawing out of alinement, the upper rail from *c* to *d*, Fig. 32, is heated, also, at the time the weld is made. The bolt *b*, which is tightened just before the mold is poured, is loosened gradually while the weld is cooling.

If the break occurs in a vertical leg, as at *a*, Fig. 33, the metal is cut away and the jack *b* is used to spring the ends apart about $\frac{1}{4}$ inch. The mold box is fitted around the vertical leg and the upper rail, and the mold for the steel collar is made in the same way as before. The pressure of the jack is eased off during the cooling of the weld.

53. Welding Valve Link.—A broken link forming part of the valve gear of a locomotive is shown in Fig. 34 (*a*). The fractures are at *a* and *b*, so that one side *c* of the link is broken out. To make the repair, the ends of the curved piece *c* are trimmed off, so that, when the piece is carefully lined up and clamped in position, gaps are left as shown in (*b*) at *d* and *e*. Molds are arranged at these points in the usual way, and thermit steel is run in. The appearance of the

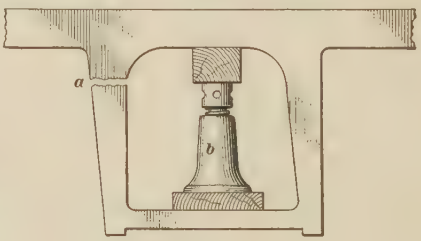

FIG. 33

repaired piece after the molds are removed is shown in (*c*). The collars of metal at *f* and *g* firmly unite the piece *c* to the body of the link. After the gates *h* and *i* are cut off and the welds are machined to the width of the link, the work will appear as in (*d*). In this particular case, the metal must be cut away considerably at the welds, a slight reinforcement being left at the points *j* and *k*. Wherever possible, however, the collars of thermit steel should be left in place, to give the necessary strength. In the case of the repaired frame shown in Fig. 31, for example, the collar would be trimmed up neatly, as shown, and not machined.

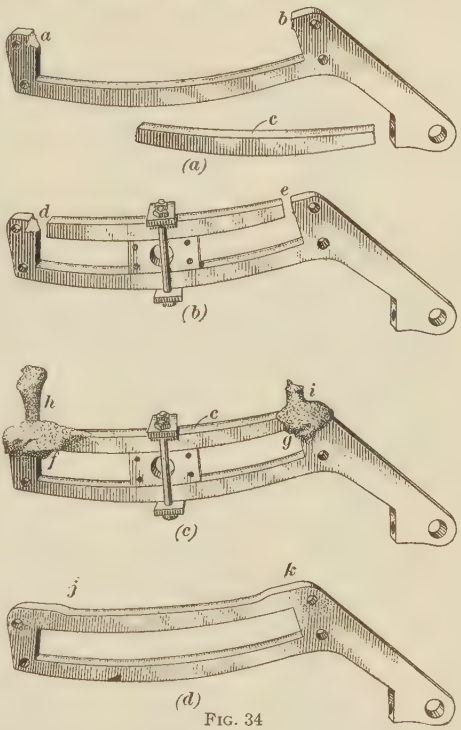

FIG. 34

54. Welding a Broken Shaft.—The application of thermit to the repair of a broken shaft is shown in Fig. 35. The

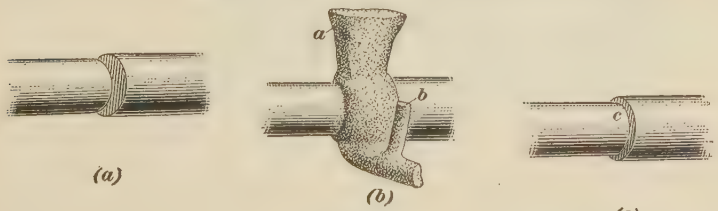

FIG. 35

break is at a shoulder where the diameter changes from 10 to 12 inches. The metal at the break is cut away, as shown in (*a*),

leaving a space $2\frac{1}{2}$ inches wide between the ends. The parts of the shaft are accurately alined and blocked in position, a wax pattern is built around the gap, and a mold is prepared. The weld when completed appears as in (*b*), in which *a* is the

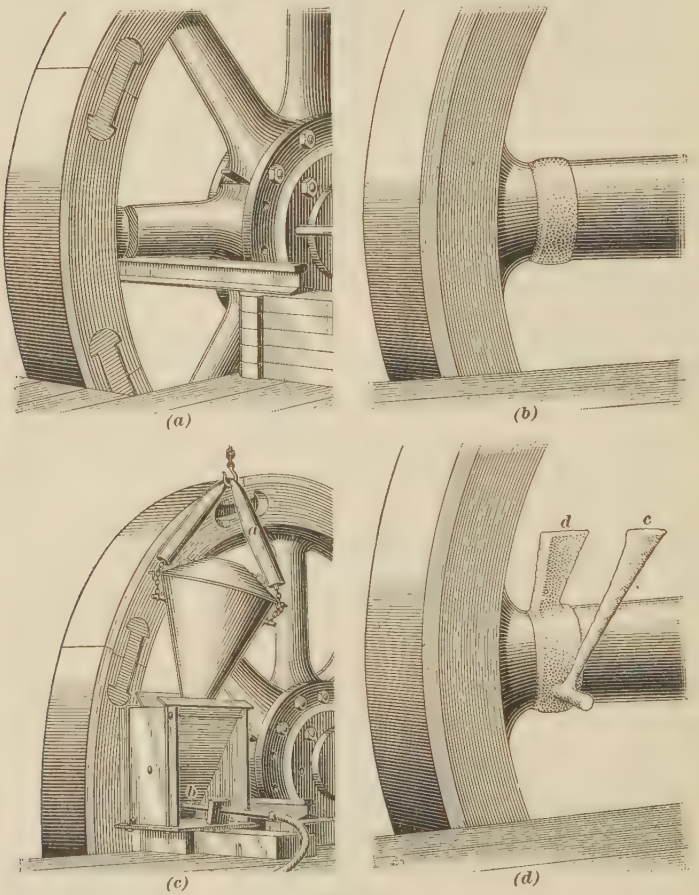

FIG. 36

riser and *b* the gate sprue. It is necessary, in this case, to trim off the collar of steel, so that the repair, when finished, will give the shaft its original appearance, as in (*c*). The strength of a weld that is made with thermit and then trimmed off to

the original form and size, as at *c*, is from 80 to 90 per cent. of the strength of the original material. A welding operation of this kind, on a shaft of this size, requires about 72 hours, at the end of which time the shaft is ready to resume service. If the shaft must be taken down and sent away, the cost of the repair will be much greater and the machinery of which it forms a part will be thrown out of use, entailing further expense.

55. Welding a Flywheel Arm.—The repair of a broken flywheel arm by the use of thermit is illustrated in Fig. 36.

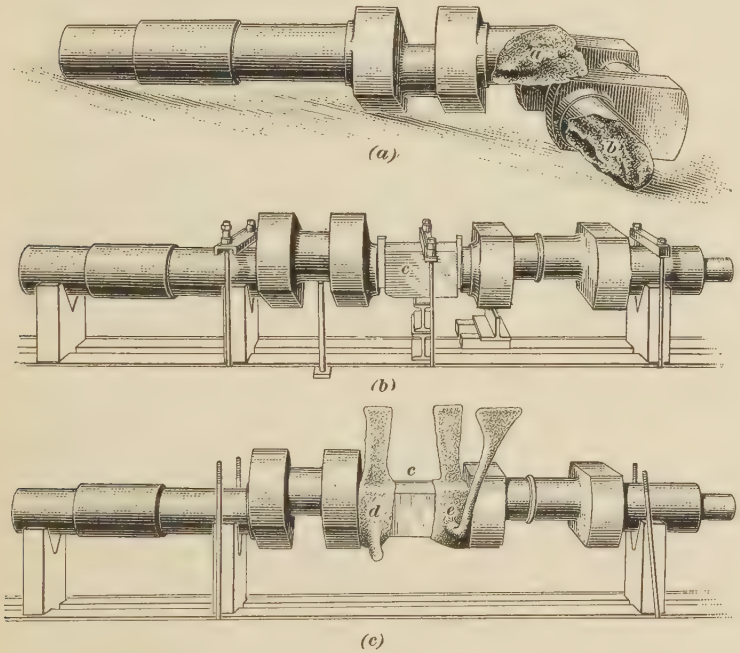

Fig. 37

The wheel is built up of eight segments, each cast solid with an arm. The break is near the rim, across one of the arms, which are oval in section and measure 5 inches by 12 inches. The metal at the fracture is chipped away, as in (*a*), and the bolts that hold the arm to the hub are taken out. The rim and the arm are carefully lined and clamped, and a wax pattern is put in

place, as in (*b*). The mold is built around the arm as in (*c*), and the thermit crucible is suspended by a sling *a*. The torch *b* is used to melt out the wax pattern and to heat the ends to redness before the mold is poured. The completed weld is shown in (*d*), with the gate *c* and the riser *d* attached. These are cut off neatly and the collar is smoothed up, leaving a ring of steel around the break.

56. Repairing a Crank-Shaft Journal.—The repair of a $9\frac{1}{4}$-inch crank-shaft of an engine broken through one of the journals is shown in Fig. 37 (*a*). The shaft is removed from the engine and the broken ends *a* and *b* are cut off close to the shoulders of the journal. The parts are then set in V blocks, as

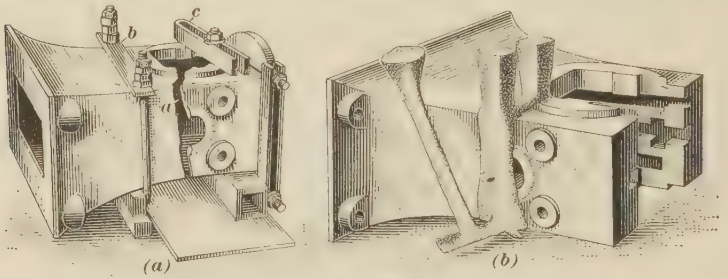

FIG. 38

shown in (*b*), and are carefully lined. Instead of using thermit steel to make a new journal, however, a block of steel is welded in. This block, about 10 inches square and 16 inches long, is set between the broken ends, as at *c*, and is rigidly clamped there. End movement is prevented by the iron wedges driven into the gaps left for the welds. Wax patterns are built around the gaps and molds are made, after which the parts to be welded are brought to a red heat and thermit steel is run in. The appearance of the work after the molds are removed is shown in (*c*), the block *c* being firmly welded between the ends of the journal. The gates and risers are cut off, the shaft is put in a lathe, and the block *c* and the steel collars *d* and *e* are turned to $9\frac{1}{4}$ inches in diameter, forming a new journal.

57. Welding a Cast-Iron Pillow-Block.—Another example of the application of thermit is shown in Fig. 38, in

which (*a*) illustrates a broken cast-iron pillow-block. The metal at the break is first cut away, leaving a gap *a*. The work is then blocked up and clamped firmly by the straps *b* and *c*. A mold of the proper shape is formed in the usual way, and the weld is made with thermit, as shown in (*b*). The gate and the risers are then knocked off and the jaw is machined on the side faces and the inside.

58. Durability of Thermit Crucible.—The best material for the lining of thermit crucibles is magnesia tar. Fireclay is but a makeshift, as it usually will be destroyed by one welding operation, and must then be replaced; whereas, if the crucible is properly lined with magnesia tar, it can be used for from 16 to 20 operations. The lining must be tamped in place firmly. To do this, a cast-iron cone having the same taper as the crucible is set into the crucible shell and wedged around the top so as to leave a space between the shell and the cone. Magnesia tar is then rammed into this space, the tamping tool being struck good, heavy blows. The cast-iron cone is then removed, wrapped with heavy wrapping paper or several thicknesses of newspaper, and put back in the crucible. The whole is then put in an oven, brought to a red heat, and kept at that point for at least six hours. This baking of the lining is very important, and when it is finished, the crucible should be allowed to cool slowly. The paper wrapping of the cast-iron cone will be charred and the cone can be removed easily. The magnesia thimble at the bottom, through which the thermit steel flows when the crucible is tapped, should also be wrapped with paper when it is inserted, to enable it to be removed easily. It must be replaced by a fresh thimble if it is cracked or worn away by the stream of hot steel.

59. Quantity of Thermit Required.—The composition of thermit is such that the amount of thermit steel produced is just half the weight of thermit used. For each cubic inch of steel required in making the weld, therefore, 9 ounces of thermit is required; hence, to find the weight of thermit, the following rule should be used:

Rule.—*To find the number of pounds of thermit required for a given weld, calculate the number of cubic inches in the weld, including the reinforcing collar, double this number, multiply the product by 9, and divide that product by 16.*

The reason for doubling the number of cubic inches in the weld and the collar is to allow for the metal in the gate and the riser; and the final product is divided by 16 to reduce it from ounces to pounds. Thus, if a certain weld is estimated to contain 35 cubic inches, including the collar, by applying the rule, the weight of thermit needed is found to be

$$\frac{35\times2\times9}{16}=40 \text{ pounds, nearly}$$

60. If wax is used, as already described, in building up a pattern for the reinforcing collar, the calculation of the weight of thermit needed may be based on the weight of wax used. The wax not only forms the pattern for the collar, but also fills the gap that is cut between the ends of the piece to be welded. If the weight of the supply of wax on hand is taken before and after the pattern is made, the weight of wax used is the difference of the two. The weight of thermit required may then be calculated by the following rule:

Rule.—*The weight of thermit, in pounds, required for a given weld is equal to 32 times the number of pounds of wax used in forming the pattern.*

Thus, if before building up the pattern for a thermit weld, the weight of wax on hand is $6\frac{1}{2}$ pounds, and after forming the pattern the weight of wax remaining is 4 pounds, the weight of wax used for the pattern is $6\frac{1}{2}-4=2\frac{1}{2}$ pounds. Then, applying the rule, the weight of thermit required is $32\times2\frac{1}{2}=80$ pounds.

61. Additions to Thermit.—If the weight of thermit required for a weld is greater than 10 pounds, clean mild-steel punchings must be mixed with the thermit, to reduce the violence of the burning. These punchings must be free from grease and not more than $\frac{1}{2}$ inch in diameter. A part of the heat developed by the burning of the thermit will be used in melting the punchings, and the resulting temperature will be reduced

somewhat, without affecting the efficiency of the weld. The proportion of punchings to be added increases with the amount of thermit used. For quantities of from 10 to 50 pounds of thermit, 10 per cent. of punchings should be added; but if more than 50 pounds of thermit is required, 15 per cent. of small mild-steel rivets may be mixed in. These percentages are based on weights.

62. If a cast-iron piece is to be welded with thermit, the best results will be obtained by the use of a special mixture made by adding to the thermit about 20 per cent. of mild-steel punchings and 3 per cent. of ferrosilicon that contains 50 per cent. of silicon. This mixture will produce a soft, uniform metal in the weld, and the machining of the repaired section will not be difficult. If the weld is of such a nature that the metal is free to expand and contract, satisfactory results can be obtained without difficulty; but if the break is in such a position that the cooling of the weld sets up shrinkage stresses in adjacent parts, trouble may be experienced through the starting of cracks near the weld.

63. The addition of steel punchings to the thermit reduces the quantity of thermit that must be used. As already stated, the amount of thermit steel produced is half the weight of thermit used. The addition of a pound of steel punchings, therefore, will increase the amount of thermit steel to the same extent as the addition of two pounds of thermit. Hence, when steel punchings are to be added, the calculated weight of thermit required must be reduced by twice the weight of punchings, to obtain the actual weight of thermit to be used. To illustrate this point, suppose that the weight of thermit required is calculated to be 80 pounds. According to Art. **61**, it is necessary to add 15 per cent. of punchings, or $.15 \times 80 = 12$ pounds of punchings. This quantity contains the same amount of steel as $2 \times 12 = 24$ pounds of thermit; therefore, the actual weight of thermit needed is $80 - 24 = 56$ pounds. The mixture of 56 pounds of thermit and 12 pounds of punchings will then produce the same weight of molten steel as would 80 pounds of thermit

64. Care in Making Thermit Welds.—When a weld is to be made with thermit, the metal on each side of the break must be cleaned of all grease and dirt. If this is not done, the grease will be burned out during the heating of the mold, leaving openings through which the molten metal may escape. The mold should be rammed up very hard, and should be at least 3 inches thick; for if the mold is not sufficiently thick and strong, the thermit steel will cut through it, spoiling the weld, wasting the thermit, and probably melting off uninjured parts of the work. The mold box should be made of plate $\frac{3}{16}$ or $\frac{1}{4}$ inch in thickness, and should be bound securely by tie-rods. The crucible should be handled carefully, to avoid cracking the lining; therefore, it is better to carry it about the shop than to haul it on a truck. The thimble at the bottom should be in good condition and properly fitted. The hole in it should not be larger than $\frac{5}{8}$ inch in diameter. As soon as the hole becomes worn to this size, the thimble should be renewed.

65. Welding Pipe.—Thermit may be used successfully for welding pipes together, end to end. The pieces to be joined are cut off squarely and are filed so that the ends, when butted together, will fit neatly. Two such pieces are shown at *a* and *b*, Fig. 39 (*a*), the squared ends meeting snugly at *c*. Strong clamps *d* are put on each section of pipe, at about 4 inches from the joint *c*, and the wing-nuts *e* are screwed down until the pipes are gripped firmly. The jaws of each clamp are slotted, and long bolts *f* are set into the slots, tying the clamps together. The nuts *g* on these bolts are drilled with holes into which rods may be set, to tighten the nuts. When the nuts *g* are screwed up on the bolts *f*, the ends of the pieces of pipe are pressed firmly together at *c*. When the pieces have been butted and clamped as shown, the two-part cast-iron mold in (*b*) is put around the ends, so that the joint *c* in (*a*) is exactly central in the mold. The cast-iron mold, shown in (*b*), has an opening *a* of the correct size to fit the pipe to be welded, and is provided with a pouring gate *b*.

66. After the pipes are clamped and the mold is put in place, the thermit is ignited in the usual way. The crucible used,

however, is not of the type that is tapped through the bottom. Instead, it is small and shallow, with a solid bottom, and is held in a pair of tongs, so that the thermit can be poured by tilting the crucible. In welding pipe with thermit, the thermit steel does not come in contact with the pipe; but it furnishes the heat required to bring the ends of the pipe to a welding heat. In about 20 or 30 seconds after the thermit has been ignited, the slag in the top of the crucible is poured into the mold surrounding the pipe. The slag that flows first adheres to the pipe in a thin layer that protects the pipe from the cutting action of the thermit steel, which is in the bottom of the crucible and is poured last. As soon as the mold is poured, pins are inserted in the holes in the nuts *g*, Fig. 39 (*a*), and the two ends of the pipe are drawn together by screwing up the nuts. The ends of the pipe will soon reach a welding heat and become soft, and this stage can be detected by the resistance to the turning of the nuts *g*. As soon as this point is reached, the nuts should be given four or five quarter-turns, at the same time, thus forcing the ends of the pipes together and completing the weld. When cool, the mold and the clamps are removed, after which the collar of slag may be knocked off very readily. The joint will show only a slight ridge at the weld, and this may be removed by machining, if desired.

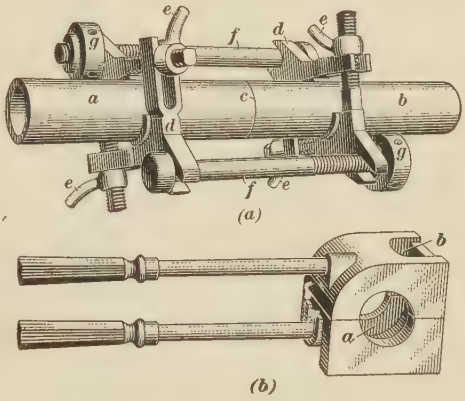

FIG. 39

TABLE I

WEIGHTS PER LINEAR FOOT AND AREAS OF SQUARE AND ROUND STEEL BARS

Side or Diameter Inches	Weight of Square Bar Pounds	Weight of Round Bar Pounds	Area of Square Bar Square Inches	Area of Round Bar Square Inches
$\frac{1}{16}$	.013	.010	.0039	.0031
$\frac{1}{8}$	.053	.042	.0156	.0123
$\frac{3}{16}$	.120	.094	.0352	.0276
$\frac{1}{4}$	.213	.167	.0625	.0491
$\frac{5}{16}$	.332	.261	.0977	.0767
$\frac{3}{8}$	.478	.376	.1406	.1104
$\frac{7}{16}$	.651	.511	.1914	.1503
$\frac{1}{2}$	.850	.668	.2500	.1963
$\frac{9}{16}$	1.076	.845	.3164	.2485
$\frac{5}{8}$	1.328	1.043	.3906	.3068
$\frac{11}{16}$	1.607	1.262	.4727	.3712
$\frac{3}{4}$	1.913	1.502	.5625	.4418
$\frac{13}{16}$	2.245	1.763	.6602	.5185
$\frac{7}{8}$	2.603	2.044	.7656	.6013
$\frac{15}{16}$	2.988	2.347	.8789	.6903
1	3.400	2.670	1.0000	.7854
$1\frac{1}{8}$	4.303	3.380	1.2656	.9940
$1\frac{1}{4}$	5.313	4.172	1.5625	1.2272
$1\frac{3}{8}$	6.428	5.049	1.8906	1.4849
$1\frac{1}{2}$	7.650	6.008	2.2500	1.7671
$1\frac{5}{8}$	8.978	7.051	2.6406	2.0739
$1\frac{3}{4}$	10.410	8.178	3.0625	2.4053
$1\frac{7}{8}$	11.950	9.388	3.5156	2.7612
2	13.600	10.680	4.0000	3.1416
$2\frac{1}{8}$	15.350	12.060	4.5156	3.5466
$2\frac{1}{4}$	17.210	13.520	5.0625	3.9761
$2\frac{3}{8}$	19.180	15.060	5.6406	4.4301
$2\frac{1}{2}$	21.250	16.690	6.2500	4.9087
$2\frac{5}{8}$	23.430	18.400	6.8906	5.4119
$2\frac{3}{4}$	25.710	20.190	7.5625	5.9396
$2\frac{7}{8}$	28.100	22.070	8.2656	6.4918
3	30.600	24.030	9.0000	7.0686
$3\frac{1}{8}$	33.200	26.080	9.7656	7.6699
$3\frac{1}{4}$	35.920	28.210	10.5630	8.2958
$3\frac{3}{8}$	38.730	30.420	11.3910	8.9462
$3\frac{1}{2}$	41.650	32.710	12.2500	9.6211
$3\frac{5}{8}$	44.680	35.090	13.1410	10.3210
$3\frac{3}{4}$	47.820	37.550	14.0630	11.0450
$3\frac{7}{8}$	51.050	40.100	15.0160	11.7930

TABLE I—(*Continued*)

Side or Diameter Inches	Weight of Square Bar Pounds	Weight of Round Bar Pounds	Area of Square Bar Square Inches	Area of Round Bar Square Inches
4	54.40	42.73	16.000	12.566
4 1/8	57.85	45.44	17.016	13.364
4 1/4	61.41	48.24	18.063	14.186
4 3/8	65.08	51.11	19.141	15.033
4 1/2	68.85	54.07	20.250	15.904
4 5/8	72.73	57.12	21.391	16.800
4 3/4	76.71	60.25	22.563	17.721
4 7/8	80.80	63.46	23.766	18.665
5	85.00	66.76	25.000	19.635
5 1/8	89.30	70.14	26.266	20.629
5 1/4	93.71	73.60	27.563	21.648
5 3/8	98.23	77.15	28.891	22.691
5 1/2	102.90	80.78	30.250	23.758
5 5/8	107.60	84.49	31.641	24.851
5 3/4	112.40	88.29	33.063	25.967
5 7/8	117.40	92.17	34.516	27.109
5	122.40	96.13	36.000	28.274
6 1/4	132.80	104.30	39.063	30.680
6 1/2	143.70	112.80	42.250	33.183
6 3/4	154.90	121.70	45.563	35.785
7	166.60	130.80	49.000	38.485
7 1/4	178.70	140.40	52.563	41.283
7 1/2	191.30	150.20	56.250	44.179
7 3/4	204.20	160.40	60.063	47.173
8	217.60	170.90	64.000	50.266
8 1/4	231.40	181.80	68.063	53.456
8 1/2	245.70	192.90	72.250	56.745
8 3/4	260.30	204.40	76.563	60.132
9	275.40	216.30	81.000	63.617
9 1/4	290.90	228.50	85.563	67.201
9 1/2	306.90	241.00	90.250	70.882
9 3/4	323.20	253.90	95.063	74.662
10	340.00	267.00	100.000	78.540
10 1/4	357.20	280.60	105.060	82.516
10 1/2	374.90	294.40	110.250	86.590
10 3/4	392.90	308.60	115.560	90.763
11	411.40	323.10	121.000	95.033
11 1/4	430.30	338.00	126.560	99.402
11 1/2	449.70	353.20	132.250	103.870

TABLE II

WEIGHTS PER LINEAR FOOT OF SQUARE AND ROUND WROUGHT-IRON BARS

Side or Diameter Inches	Weight of Square Iron Pounds	Weight of Round Iron Pounds	Side or Diameter Inches	Weight of Square Iron Pounds	Weight of Round Iron Pounds
$\frac{1}{16}$	.013	.010	$4\frac{3}{8}$	64.700	50.810
$\frac{1}{8}$	.053	.041	$\frac{1}{2}$	68.450	53.760
$\frac{3}{16}$	.118	.093	$\frac{5}{8}$	72.300	56.790
$\frac{1}{4}$	.211	.165	$\frac{3}{4}$	76.260	59.900
$\frac{3}{8}$	.475	.373	$\frac{7}{8}$	80.330	63.090
$\frac{1}{2}$	.845	.663	5	84.480	66.350
$\frac{5}{8}$	1.320	1.043	$\frac{1}{8}$	88.780	69.730
$\frac{3}{4}$	1.901	1.493	$\frac{1}{4}$	93.170	73.170
$\frac{7}{8}$	2.588	2.032	$\frac{3}{8}$	97.660	76.700
1	3.380	2.654	$\frac{1}{2}$	102.240	80.300
$\frac{1}{8}$	4.278	3.359	$\frac{5}{8}$	106.950	84.000
$\frac{1}{4}$	5.280	4.147	$\frac{3}{4}$	111.750	87.770
$\frac{3}{8}$	6.390	5.019	$\frac{7}{8}$	116.670	91.630
$\frac{1}{2}$	7.604	5.972	6	121.660	95.550
$\frac{5}{8}$	8.926	7.010	$\frac{1}{4}$	132.040	103.700
$\frac{3}{4}$	10.352	8.128	$\frac{1}{2}$	142.820	112.160
$\frac{7}{8}$	11.883	9.333	$\frac{3}{4}$	154.010	120.960
2	13.520	10.620	7	165.630	130.050
$\frac{1}{8}$	15.263	11.990	$\frac{1}{4}$	177.670	139.540
$\frac{1}{4}$	17.112	13.440	$\frac{1}{2}$	190.140	149.330
$\frac{3}{8}$	19.066	14.980	$\frac{3}{4}$	203.020	159.460
$\frac{1}{2}$	21.120	16.590	8	216.330	169.860
$\frac{5}{8}$	23.292	18.290	$\frac{1}{4}$	230.060	180.700
$\frac{3}{4}$	25.560	20.080	$\frac{1}{2}$	244.220	191.810
$\frac{7}{8}$	27.939	21.940	$\frac{3}{4}$	258.800	203.260
3	30.416	23.890	9	273.790	215.040
$\frac{1}{8}$	33.010	25.930	$\frac{1}{4}$	289.220	227.150
$\frac{1}{4}$	35.704	28.040	$\frac{1}{2}$	305.060	239.600
$\frac{3}{8}$	38.500	30.240	$\frac{3}{4}$		252.380
$\frac{1}{2}$	41.408	32.510	10		265.400
$\frac{5}{8}$	44.420	34.890	$\frac{1}{4}$		278.920
$\frac{3}{4}$	47.534	37.330	$\frac{1}{2}$		292.690
$\frac{7}{8}$	50.760	39.860	$\frac{3}{4}$		306.800
4	54.080	42.460	11		321.220
$\frac{1}{8}$	57.510	45.170	$\frac{1}{4}$		336.000
$\frac{1}{4}$	61.050	47.950	$\frac{1}{2}$		351.100

TABLE III

WEIGHTS PER LINEAR FOOT OF FLAT WROUGHT-IRON BARS

Breadth Inches	Thickness, in Inches								
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
	Weight, in Pounds								
1	.83	1.04	1.25	1.46	1.67	2.08	2.50	2.92	3.34
$1\frac{1}{8}$	.93	1.17	1.40	1.64	1.87	2.34	2.81	3.28	3.75
$1\frac{1}{4}$	1.04	1.30	1.56	1.82	2.08	2.60	3.13	3.65	4.17
$1\frac{3}{8}$	1.14	1.43	1.72	2.00	2.29	2.87	3.44	4.01	4.59
$1\frac{1}{2}$	1.25	1.56	1.87	2.19	2.50	3.13	3.75	4.38	5.00
$1\frac{5}{8}$	1.35	1.69	2.03	2.37	2.71	3.39	4.07	4.70	5.43
$1\frac{3}{4}$	1.46	1.82	2.19	2.55	2.92	3.65	4.38	5.11	5.84
$1\frac{7}{8}$	1.56	1.95	2.34	2.74	3.13	3.92	4.69	5.47	6.26
2	1.67	2.08	2.50	2.92	3.34	4.17	5.01	5.86	6.68
$2\frac{1}{8}$	1.77	2.21	2.66	3.10	3.55	4.43	5.32	6.21	7.10
$2\frac{1}{4}$	1.87	2.34	2.81	3.28	3.76	4.69	5.63	6.57	7.52
$2\frac{3}{8}$	1.98	2.47	2.97	3.47	3.96	4.95	5.95	6.94	7.93
$2\frac{1}{2}$	2.08	2.60	3.13	3.65	4.17	5.21	6.26	7.30	8.35
$2\frac{5}{8}$	2.19	2.74	3.28	3.83	4.38	5.47	6.57	7.67	8.77
$2\frac{3}{4}$	2.29	2.87	3.44	4.01	4.59	5.74	6.88	8.03	9.18
$2\frac{7}{8}$	2.40	3.00	3.60	4.20	4.80	6.00	7.20	8.40	9.60
3	2.50	3.13	3.75	4.38	5.01	6.26	7.51	8.76	10.02
$3\frac{1}{4}$	2.71	3.39	4.07	4.74	5.43	6.78	8.14	9.49	10.86
$3\frac{1}{2}$	2.92	3.65	4.38	5.11	5.84	7.30	8.76	10.23	11.69
$3\frac{3}{4}$	3.13	3.91	4.68	5.47	6.26	7.82	9.39	10.95	12.52
4	3.34	4.17	5.00	5.84	6.68	8.35	10.02	11.69	13.36
$4\frac{1}{4}$	3.54	4.43	5.32	6.21	7.09	8.87	10.64	12.42	14.19
$4\frac{1}{2}$	3.75	4.69	5.63	6.57	7.51	9.39	11.27	13.15	15.03
$4\frac{3}{4}$	4.06	4.95	5.94	6.94	7.93	9.91	11.89	13.88	15.86
5	4.17	5.21	6.26	7.30	8.35	10.44	12.52	14.61	16.70
$5\frac{1}{4}$	4.38	5.47	6.57	7.67	8.76	10.96	13.14	15.34	17.53
$5\frac{1}{2}$	4.59	5.73	6.88	8.03	9.18	11.48	13.77	16.07	18.37
$5\frac{3}{4}$	4.80	6.00	7.20	8.40	9.60	12.00	14.40	16.80	19.20
6	5.01	6.25	7.51	8.76	10.02	12.53	15.03	17.53	20.05